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INTRODUCTION

Volume II presents detailed test plans for the individual system tests described in Section 2.0 of Volume I. These detailed test plans define the manner in which the approved subcontractor and S&ID will accomplish the testing required to qualify the subassemblies and individual systems for inclusion in the Apollo spacecraft.

Included in each test plan will be information regarding the equipment and configuration of the test article; test concepts and objectives; test locations; data requirements, receiving, acceptance, and checkout tests; significant test procedures; and other essential information.

In general, tests on components of subcontractor-furnished systems will not be performed by S&ID.

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1.0 SERVICE PROPULSION SYSTEM

1.1 SCOPE

This section consists of the development test program for the service propulsion system. It is divided into two main sections: (1) the subcontractor (Aerojet General) test program and (2) S&ID's development test program. The section is limited to engineering development, evaluation, and design verification tests. Qualification tests are covered in SID 62-109-3.

The subcontractor's development test program consists of a preliminary development test program, a simulated high-altitude test program, and a development evaluation test program. The development test program of S&ID consists of two phases of tests at the breadboard level to determine subsystems compatibility, verification of component supplier's test results and evaluation of the system prior to the integrated systems test.

1.2 SUBCONTRACTOR TEST PLAN (AEROJET-GENERAL)

1.2.1 Thrust Chamber and Injector Preliminary Development Test Plan (Phase I)

1.2.1.1 Objective

The objective of this test plan is to develop, optimize, and verify performance and configuration of a rocket engine complying to the requirements of S&ID Procurement Specification NC901-0009.

1.2.1.2 Test Plan

1.2.1.2.1 Injector Pattern. To determine the injector configuration and performance characteristics, injectors have been designed to various configurations and tested to develop the optimum configuration. Testing will be accomplished with work-horse chambers, which will contribute to ultimate chamber geometry definition. Approximately 124 tests will be performed, using 18 experimental injectors, 3 steel test chambers, and 4 steel chamber sections. Tests will include induced instability, fuel and oxidizer ratio investigation, and altitude starts.

1.2.1.2.2 Stabilized Operation. Tests will be conducted to optimize the injector orifice length over diameter ratio, investigate combustion

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stability, evaluate injector face cooling, and obtain preliminary heat transfer data. Mixture ratio variations will be investigated for off-design engine operation. Approximately 76 tests will be performed using 2 experimental injectors, 13 test chambers, and experimental propellant valves.

1.2.1.2.3 Chamber Material. Tests will be conducted on chambers of alternate materials and bonding agents for comparison with chambers of phenolic-refrasil construction. These tests will determine the optimum materials currently available for thrust chamber usage. This series of tests is to be conducted in three phases as follows:

1. Preliminary evaluation. Testing of material specimens with laboratory type equipment.

2. Subscale tests. Subscale chambers of various ablative materials will be fired at both sea-level and altitude conditions. Approximately 90 tests are to be performed on approximately 18 chambers at sea level conditions, and 6 subscale chambers are to be expended with a total of 102 firings at altitude (AEDC). Nozzle extensions will be evaluated during the AEDC tests.

3. Full-scale tests. 12 full-scale tests utilizing 4 chambers will be conducted for final evaluation.

1.2.1.2.4 Compatibility. Approximately 50 tests will be conducted, utilizing 11 chambers for the following purposes:

1. To verify injector/chamber compatibility
2. To evaluate flange
3. To demonstrate restart capability
4. To finalize wall thickness
5. To demonstrate performance at high and low temperature
6. To demonstrate performance with abnormal start pressures
7. To investigate effects of plugged injector
8. To demonstrate performance with abnormally high chamber pressure (P_c)

9. To verify prototype flight weight chamber performance and capabilities under conditions of high and low mixture ratio, high and low temperature, abnormal starting pressure, above normal P_c, and abort mission firing duration

To evaluate gimbal actuator performance characteristics and durability while subjected to varying environmental conditions, several actuators will be operated while they are subjected to shock, high and low temperature, vibration, etc.

1.2.1.2.5 Nozzle Extension. Tests will be conducted to provide preliminary evaluation of the nozzle extension configuration, material selection, and chamber nozzle attach flange location and configuration. Tests will be conducted on various nozzle and joint configurations using nonaugmented straight pipe diffusers.

1.2.1.2.6 Engine Mounts. The test program is designed to evaluate the structural integrity of the engine mounts, to verify load carrying capabilities, and to determine failure loads. This test program will include component tests, cyclic and shock-loading tests, and a rotational resonant frequency test of the complete mount.

1.2.1.2.7 Propellant Lines. Tests will be conducted to develop and verify propellant line configuration.

1.2.1.3 Equipment

Aerojet test facilities will be equipped with thrust measuring stands, tankage, pressurization systems, altitude chambers, environmental simulation equipment, and high-response recording and measuring instruments. ARO, Incorporated (Tullahoma) equipment will be used for AEDC tests.

1.2.1.4 Facilities

The development tests of the service propulsion engine system (see Table 1-1) will be conducted at Azusa and Sacramento, California, and at the AEDC facility at Tullahoma, Tennessee.

[redacted]

Table 1-1. Service Propulsion Engine System Development Tests

Tests	Facility	Location
Injector pattern	Building 23A	Azusa
Stabilized operation	Building 23C	Azusa
Chamber material	Building 23C T-4	Azusa (AEDC) Tullahoma
Compatibility	Building 23C Building 23A H-1 C-10	Azusa Azusa Sacramento Sacramento
Nozzle extension	H-3	Sacramento
Engine mounts	Building 135 Building 42	Azusa Azusa
Propellant lines	Building 42	Azusa

1.2.2 Thrust Chamber Valve Preliminary Development Test Plan

1.2.2.1 Objective

Development tests will be performed on thrust chamber valve clusters prior to qualification and/or production to fully analyze the component function and ability to withstand environments. Development tests consist of functional and environmental tests considered critical to valve operation.

1.2.2.2 Test Plan

1.2.2.2.1 Functional. Tests will be performed to allow functional evaluation of the thrust chamber valves on a component level. Transient flow characteristics, burst pressure tests, actuation rates, proof pressure, and leak evaluation tests will be conducted. Two experimental and four pre-prototype valves will be used in the tests.

1.2.2.2.2 Environmental. Several valve assemblies will be operated while being subjected to high and low temperatures, high and low voltage, and vibration and acoustic environments. Life duty cycling also will be accomplished.

[redacted]

1.2.2.3 Equipment

All necessary equipment will be provided by AGC.

1.2.2.4 Facilities

Thrust chamber valve functional and environmental development tests will be performed in Building 135 at Azusa, California.

1.2.3 Gimbal Actuator Preliminary Development Test Plan

1.2.3.1 Objective

Development testing of the gimbal actuation system will be conducted in two phases. The first phase will consist of testing performed at the actuator level to establish functional and structural integrity of the actuator as a component.

The second phase of the testing will be conducted on gimbal actuator systems that will include the engine loads, structural compliance, damping and compensation networks, and the servo amplifier as well as the actuator. The purpose of these tests will be to develop a thrust vector control system that meets the response characteristics demanded by the vehicle guidance system and is compatible with the engine and supporting structure dynamics.

The service module structure is sufficiently complex to make it virtually impossible to simulate. The characteristics of this structure will dominate the selection of gains, damping factors, and compensation devices. For these reasons, development testing on a "hard" test stand will not be useful in establishing final stability and response characteristics. That can only be accomplished in an actual flight-weight service module structure or with a good computer simulation. These tests can be useful, however, in establishing actuator and gimbal characteristics for use in computer studies as well as for environmental testing.

1.2.3.2 Test Plan

1.2.3.2.1 Functional (Phase I). Tests will be performed to:

1. Establish hysteresis, dead band, and linearity for low-amplitude control signal inputs.

2. Establish response capabilities and step and sinusoidal inputs at varying amplitudes and frequencies. Tests to establish power

demands under various conditions of load with step, ramp, and sinusoidal inputs at varying amplitudes and frequencies are not expected to be made.

3. Determine structural integrity and stiffness of actuator assembly

4. Establish operating life and durability under simulated operational environments including extended exposure to high vacuum.

5. Evaluate dielectric strength and insulation resistance of all electrical components.

1.2.3.2.2 Functional (Phase II). Tests will be performed to:

1. Establish tentatively response characteristics with simulated inertial, spring and friction loads, with simulated structural compliances and with varying damping factors. These tests are to establish tentatively the limiting gains and damping required in the minor loop to provide satisfactory control and response to low-amplitude, low-frequency inputs as well as satisfactory response and stability for larger-amplitude, high-frequency inputs.

2. Develop parametric data by utilizing identically programmed inputs for cold-gimbaling, multiple-restart, simulated flight-duty-cycle tests.

3. Verify structural and dynamic compatibility using the same taped program input utilized in 2 with flight-weight structure and engine assemblies.

4. Determine effects of engine operational environments on the actuator control capabilities. Cold and hot gimbaling tests will be made on engines being fired. Inputs identical to those in 2 and 3 will be used.

1.2.3.2.3 Environmental. Tests will be conducted on the development actuators to establish tentatively capability to function satisfactorily during and after exposure to the environments of shock, vibration, acceleration, and temperature extremes. Units will be operated before, during, and after each test to establish the effects of each environment.

1.2.3.3 Equipment

All equipment for gimbal actuator tests is to be supplied by AGC. It should be noted that AGC has chosen circuitry for their servo amplifier different from Minneapolis-Honeywell (whose amplifier is not available for these tests).

1.2.3.4 Facilities

Gimbal actuator tests will be conducted in Building 135 at Azusa, California, and "C" area at Sacramento, California.

1.2.4 Simulated High-Altitude Tests (Phase II - Design Evaluation)

1.2.4.1 Objective

The objective of this program is to evaluate the following operating characteristics of the S/P engine at altitudes above 110,000 feet:

1. Performance of the nozzle extension
2. Engine operation at abnormal levels of P_c and mixture ratio (O/F)
3. Engine operation when supplied with propellants from only one bank of valves
4. Effect of gimbaling the engine
5. Ablation characteristics, char depth, and life capability of the ablative chamber
6. The surface temperature profile of ablative chamber and nozzle extension
7. The effects of heat "soak-back" on injector and valves during coast periods
8. Start and shutdown impulse characteristics
9. Thrust coefficient (Cf) and specific impulse (Isp)

1.2.4.2 Test Plan

Table 1-2 outlines the tests to be performed at AEDC during the simulated high-altitude design evaluation tests. Three engines will be expended.

1.2.4.3 Equipment

All equipment for this series of tests is to be furnished by AGC or ARO.

1.2.4.4 Facilities

This series of tests is to be conducted in existing AEDC facilities at Tullahoma, Tennessee.

Table 1-2. AEDC High-Altitude Design Evaluation Tests

Test Number	Number of Firings	Firing-Duration (sec)	Hardware or Conditions	Remarks
Engine No. 1	1	10	Checkout firing	Thrust vector measurement with 60:1 nozzle on all tests
	1	40	High manufacturing tolerance nozzle	
	1	50	Low manufacturing tolerance nozzle	
	1	50	Low manufacturing tolerance nozzle, Single-valve (A) operated	
	1	50	Single-valve (A) operated High manufacturing tolerance nozzle	
	1	50	Alternate-valve (B) operated, High-manufacturing tolerance nozzle	
	1	50	Single valve (B) operated Low manufacturing tolerance nozzle	
	1	300	Double-valve operation	
	1	120	Nozzle pierced prior to test	

Table 1-2. AEDC High-Altitude Design Evaluation Tests (Cont)

Test Number	Number of Firings	Firing-Duration (sec)	Hardware or Conditions	Remarks
2	1	60	Simulated preflight firing	Thrust vector measurement with 60:1 nozzle
Engine No. 2	1	17	1st firing of mission profile, Coast 30 minutes	
	1	7	Coast 30 minutes	
	1	7	Coast 30 minutes	
	1	400	Coast 12 hours	
	19	5	Coast 1 minute	
	1	5	Coast 1 hour	
	1	110	Coast 8 hours	
	1	5	Coast 30 minutes	
	1	2	Coast 30 minutes	
	1	12	Coast 30 minutes	Thrust vector measurement with 60:1 nozzle
3	1	30	Acceptance test	Thrust vector measurement without nozzle
(New chamber on engine No. 1)	1	60	Simulated preflight firing	Thrust vector measurement with 60:1 nozzle
	1	18	30-minute coast	Simulated abort mission
	1	635	8-hour coast	Gimbal test
	1	2	30-minute coast	Gimbal test
	1	5	30-minute coast	Thrust vector measurement with 60:1 nozzle

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Table 1-2. AEDC High-Altitude Design Evaluation Tests (Cont)

Test Number	Number of Firings	Firing-Duration (sec)	Hardware or Conditions	Remarks
4	1	60	Simulated preflight firing	Thrust vector measurement with 60:1 nozzle
Engine No. 3	1	18	Coast 30 minutes	
	1	Continuous firing until 43,500 lb of propellant are consumed	High P_c, Coast 8 hours	
	1	2	High P_c, coast 30 minutes	
	1	5	High P_c, coast 30 minutes	Thrust vector measurement with 60:1 nozzle
5	1	30	Acceptance test	Thrust vector measurement with 60:1 nozzle
(New chamber on engine No. 2)	1	60	Simulated preflight firing	
	1	17	1st firing of mission profile, Coast 30 minutes	
	1	7	Coast 30 minutes	
	1	7	Coast 30 minutes	
	1	100	Coast 4 hours, high M. R.	
	1	300	Coast 8 hours, high M. R.	
	1	100	Coast 4 hours, high M. R.	

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Table 1-2. AEDC High-Altitude Design Evaluation Tests (Cont)

Test Number	Number of Firings	Firing-Duration (sec)	Hardware or Conditions	Remarks
5 (Cont)	1	50	Coast 1 hour, high M. R.	
	1	5	Coast 30 minutes, high M. R.	
	1	5	Coast 30 minutes, high M. R.	Thrust vector measurement with 60:1 nozzle
6	1	30.0	Acceptance test	Thrust vector measurement without nozzle
(New chamber on engine No. 3)	1	60.0	Preflight firing	Thrust vector measurement with 60:1 nozzle
	5	0.400	30-second coast between firings	
	5	0.500		
	5	0.600		
	5	0.800		
	5	1.0		
	5	2.0		
	5	4.0		
	5	5.0		
	5	60.0		Gimbal test
	1	290.0	Low chamber pressure	Thrust vector measurement with 60:1 nozzle

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Table 1-2. AEDC High-Altitude Design Evaluation Tests (Cont)

Test Number	Number of Firings	Firing-Duration (sec)	Hardware or Conditions	Remarks
7	1	30	Acceptance test	Thrust vector measurement without nozzle
(New chamber on engine No. 2)	1	60	Simulate preflight firing	Thrust vector measurement with 60:1 nozzle
	1	17	30-minute coast	Mission profile
	1	7	30-minute coast	Gimbal test
	1	7	30-minute coast	Gimbal test
	1	400	12-hour coast	Gimbal test
	19	5	1-minute coast	Gimbal test
	1	5	1-hour coast	Gimbal test
	1	110	8-hour coast	Gimbal test
	1	5	30-minute coast	Gimbal test
	1	2	30-minute coast	Gimbal test
	1	12	30-minute coast	Thrust vector measurement with 60:1 nozzle

Note: Engines No. 1, 2, and 3 will be subjected to a 30-sec duration checkout firing at Azusa prior to testing at AEDC.

1.2.5 Service Propulsion Prequalification Tests (Phase III)

1.2.5.1 Objective

The objectives of this program are as follows:

1. To demonstrate chamber duration, ability to perform mission duty cycles and intermittant restarts

2. Duration testing of thrust chamber valves at nominal and environmental conditions

3. Duration testing of gimbal actuators under simulated load and environmental conditions

1.2.5.2 Test Plan

1.2.5.2.1 Thrust Chamber Tests. These tests will be conducted to accomplish the following:

1. Incremental design duration. Six chambers will be expended. Each chamber will be fired in 200-second increments until failure occurs.

2. Integral design duration. Ten chambers will be expended. Each chamber will be fired for 500 seconds, 250 seconds, and a final firing to failure.

3. Mission profile. Eight chambers will be expended by firing in a manner representing a simulated mission profile.

4. Restarts. Two chambers will be subjected to short-duration restarts (125 each) until failure occurs.

1.2.5.2.2 Thrust Chamber Valve. Five valve assemblies will be subjected to life and environmental testing.

1.2.5.2.3 Gimbal Actuators. Ten gimbal actuators will be subjected to life and environmental testing.

1.2.5.3 Equipment

Chamber tests (1.2.5.2.1) will require the NAA-S&ID F-1 test fixture. All other equipment will be supplied by AGC.

1.2.5.4 Facilities

Chamber tests (1.2.5.2.1) will be conducted in the C-11 stand at Sacramento. Valve and actuator tests (1.2.5.2.2 and 1.2.5.2.3) are to be accomplished in Building 135 at Azusa.

A.G.C. will provide all equipment for thrust chamber valve and gimbal actuator tests (1.2.5.2.2 and 1.2.5.2.3).

1.2.6 Test Schedule

The subcontractor test schedule is shown in Figure 1-1.

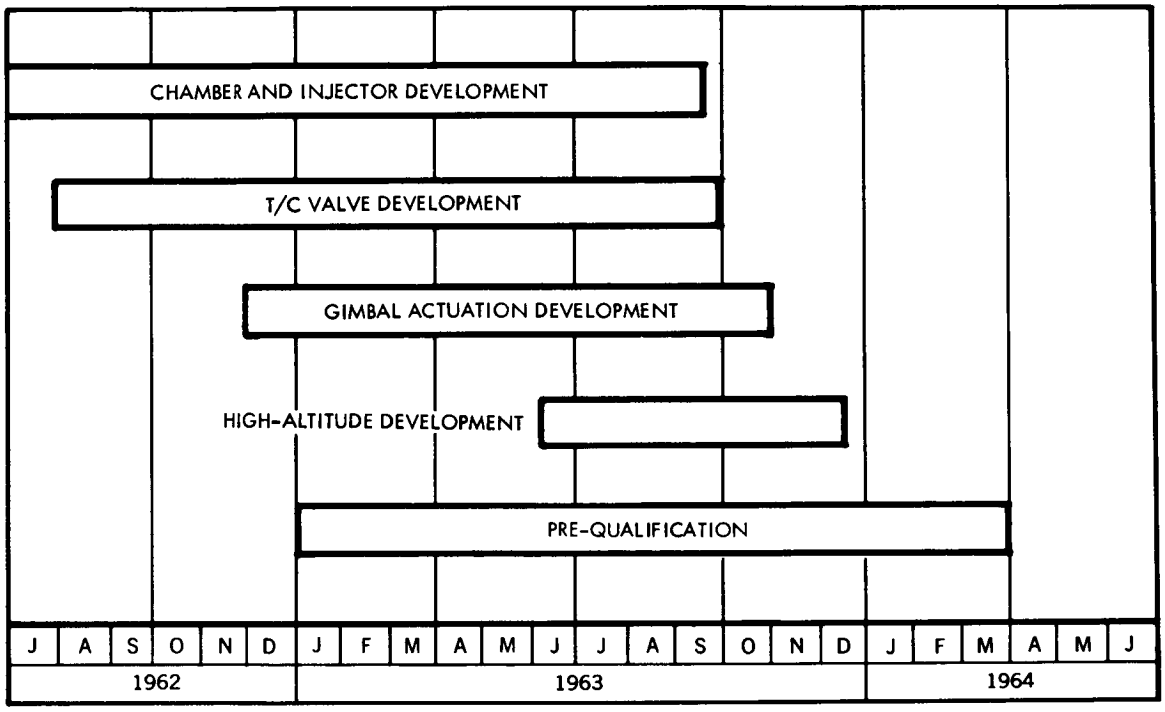

Figure 1-1. Service Module Propulsion Subcontractor Test Schedule

1.3 S&ID TEST PLAN

1.3.1 SPS Propellant System Test Plan

The development of the SPS propellant system will be accomplished by utilizing three test fixtures. These test fixtures are designated F-1, F-2, and F-3. The F-1 will be utilized to provide propellant system operational data that will be obtained during the Aerojet rocket engine tests.

The F-3 will be utilized to provide preliminary evaluation of the propellant system through the use of cold flow tests. The F-2 (see Section 4.0 of Volume V) will be the primary propellant system development tool. All problems encountered during F-1 tests, F-3 tests, and AFRM 001 tests will be investigated and corrected on the F-2 fixture. A test plan involving the use of the F-1 and F-3 fixtures is detailed below.

1.3.1.1 F-1 Test Plan

The F-1 test fixture will consist of a structural steel framework to which are attached stainless steel fuel and oxidizer tanks, stainless steel helium bottles, and off-the-shelf propellant system components. The primary purpose of the F-1 test fixture is to provide a simulated propellant feed system to ensure that rocket engine performance will be compatible with spacecraft propellant feed system dynamics. The test fixture will be used during the rocket engine development evaluation program (paragraph 1.2.5) and will also be utilized in the rocket engine qualification and acceptance test programs as outlined in Volumes III and IV.

A secondary purpose of the test fixture is to provide propellant system operational data. This data will be obtained during the Aerojet engine tests.

1.3.1.1.1 Objectives. The use of the F-1 test fixture in conjunction with Aerojet rocket engine tests will support the development of the propellant system. The test program will provide evaluation of individual components, evaluation of subsystems and their interactions, and data to prove design concepts.

1.3.1.1.2 Test Plan. The test plan will consist entirely of rocket engine tests performed by Aerojet at its Sacramento facility. During the engine test programs, however, the following list of propellant system data will be monitored and recorded:

1. Pressure of helium in helium tank
2. Temperature of helium in helium tank
3. Solenoid valve No. 1 position
4. Regulator No. 1 inlet pressure
5. Regulator No. 1 inlet temperature
6. Regulator No. 1 outlet pressure
7. Regulator No. 1 outlet temperature

8. Solenoid valve No. 2 position
9. Regulator No. 2 inlet pressure
10. Regulator No. 2 inlet temperature
11. Regulator No. 2 outlet pressure
12. Regulator No. 2 outlet temperature
13. Check valve No. 1 outlet pressure
14. Check valve No. 2 outlet pressure
15. Oxidizer tank No. 1 inlet pressure
16. Oxidizer tank No. 1, temperature No. 1
17. Oxidizer tank No. 1, temperature No. 2
18. Oxidizer tank No. 1, temperature No. 3
19. Oxidizer tank No. 1, temperature No. 4
20. Oxidizer tanks connecting-line pressure
21. Oxidizer tank No. 2 inlet pressure
22. Oxidizer tank No. 2, temperature No. 1
23. Oxidizer tank No. 2, temperature No. 2
24. Oxidizer tank No. 2, temperature No. 3
25. Oxidizer tank No. 2, temperature No. 4
26. Fuel tank No. 1 inlet pressure
27. Fuel tank No. 1, temperature No. 1
28. Fuel tank No. 1, temperature No. 2
29. Fuel tank No. 1, temperature No. 3
30. Fuel tank No. 1, temperature No. 4

31. Fuel tanks connecting-line pressure

32. Fuel tank No. 2 inlet pressure

33. Fuel tank No. 2, temperature No. 1

34. Fuel tank No. 2, temperature No. 2

35. Fuel tank No. 2, temperature No. 3

36. Fuel tank No. 2, temperature No. 4

37. Fuel tank No. 2 flow valve actuation pressure

38. Oxidizer tank No. 2 flow valve actuation pressure

39. Oxidizer flowmeter inlet pressure

40. Oxidizer flowmeter inlet temperature

41. Oxidizer flowmeter outlet pressure

42. Oxidizer flowmeter outlet temperature

43. Oxidizer flow rate

44. Fuel flowmeter inlet pressure

45. Fuel flowmeter inlet temperature

46. Fuel flowmeter outlet pressure

47. Fuel flowmeter outlet temperature

48. Fuel flow rate

1.3.1.1.3 Equipment Requirements. The equipment required to accomplish the objectives of the test program will include the F-1 test fixture; pressure, temperature, and flow-sensing elements; indicating and recording equipment; and miscellaneous support equipment.

The F-1, as previously described, will consist of a structural steel framework to which are attached ASME coded gas and propellant tanks and the numerous components which make up the pressurization and propellant distribution subsystems. The F-1 fixture will be designed and fabricated

by S&ID. After checkout at S&ID, the fixture will be shipped to the Sacramento facility of Aerojet General Corporation.

The pressure, temperature, and flow-sensing elements and indicating and recording equipment will be furnished by Aerojet.

1.3.1.1.4 Facilities. The testing will be accomplished at the Sacramento testing facility of Aerojet General Corporation.

1.3.1.1.5 Test Schedule. The test schedule for the F-1 development tests is shown in Figure 1-2.

1.3.1.2 F-2 Test Plan

See Section 4.0 of Volume V for the F-2 detailed test plan.

1.3.1.3 F-3 Test Plan

The F-3 test fixture will be similar in construction to the F-1 and F-2. It will consist of a structural steel framework to which are attached stainless steel fuel and oxidizer tanks, stainless steel helium bottles, and off-the-shelf propellant system components.

The F-3 fixture will be a dual-purpose testing tool. It will be used initially to test the propellant system of the SPS. Upon completion of this test program, the F-3 will be used to support the engine simulated altitude qualification program.

During the propellant system development tests, a simulated engine will be attached to the test fixture. The simulated engine will consist of solenoid valves which will replace the rocket engine injector valves and a flow and pressure control device which will provide an equivalent engine back pressure. The testing of the F-3 SPS propellant system will involve the use of simulated propellants as well as off-the-shelf components.

The Aerojet SPS engines will be tested in conjunction with the F-3 during the simulated altitude qualification test program at AEDC.

1.3.1.3.1 Objectives. The testing of the F-3 propellant system will accomplish the following objectives:

1. Provide experimental evaluation of the integrated system and its components and subsystems.

2. Prove design concepts and resolve design difficulties

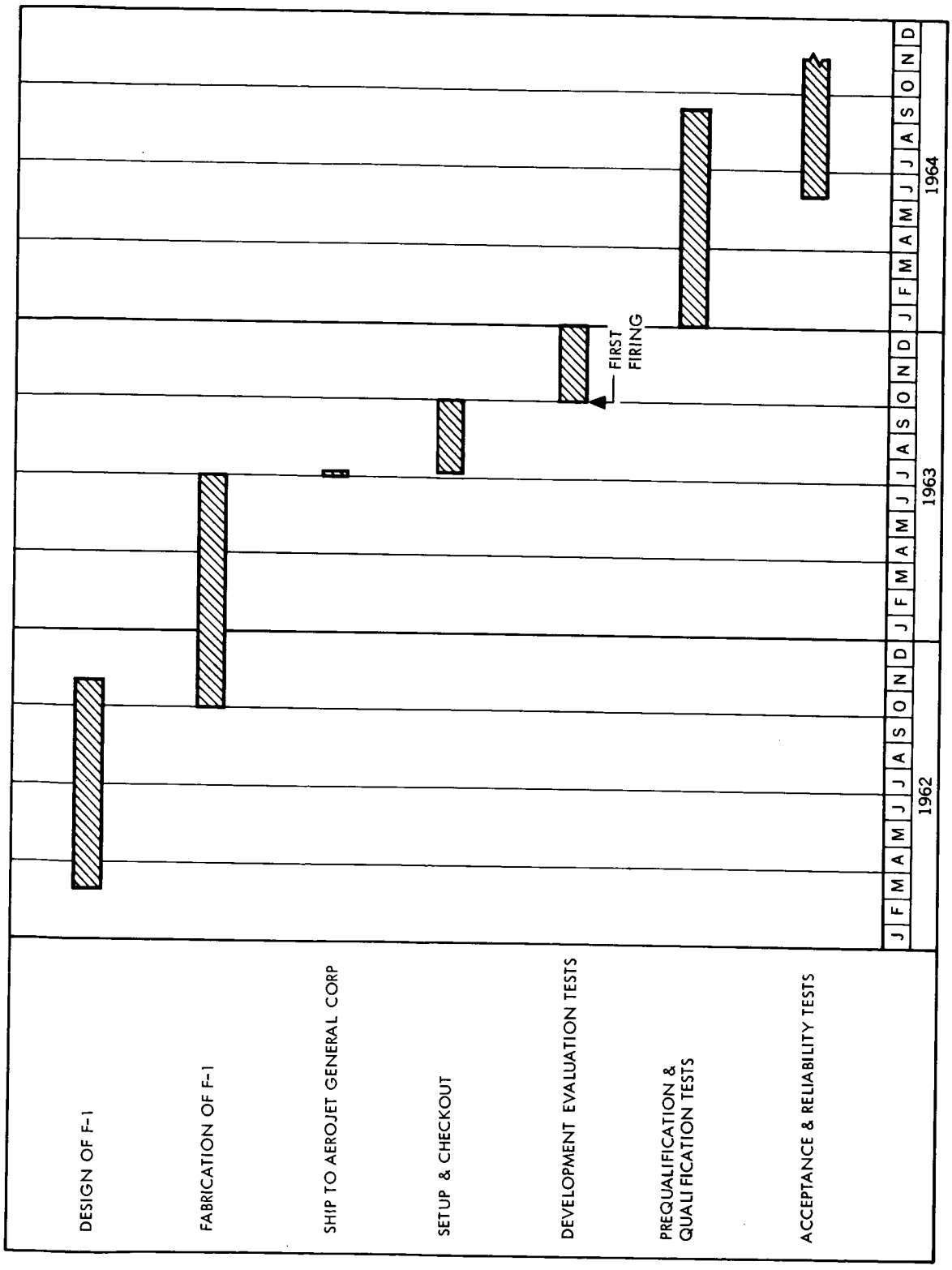

Figure 1-2. Test Fixture Test Schedule

[redacted]

3. Familiarize design and test personnel with the assembled system and ensure compatibility of components

4. Establish plumbing and component assembly techniques

5. Establish system check-out procedures

1.3.1.3.2 Test Plan. The three general types of tests that will be conducted on the F-3 propellant system are as follows:

1. Evaluation of the system during normal operation

2. Investigation of the system during off-limit operations

3. Investigation of plumbing and component assembly techniques

During the conduction of the above types of tests, techniques covering the filling, draining, and purging of the system will be evaluated.

1.3.1.3.2.1 Data Requirements. During the above tests of the SPS propellant system, the following information list will be monitored and recorded:

1. Pressure of gas in helium tank

2. Temperature of gas in helium tanks

3. Regulator inlet pressure

4. Regulator outlet pressure

5. Pressure of water at exit of oxidizer tank

6. Pressure of water at exit of fuel tank

7. Pressure at inlet of PU subsystem

8. Pressure at exit of PU subsystem

9. Displayed quantity of water in oxidizer tank

10. Actual quantity of water in oxidizer tank

11. Displayed quantity of water in fuel tank

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12. Actual quantity of water in fuel tank

13. Propellant utilization valve positions

14. Pressure at inlet to simulated rocket engine injector valves

15. Flow rate of water in oxidizer lines

16. Flow rate of water in fuel lines

17. Lapse time of test runs

1.3.1.3.2.2 Test Procedures. A detailed test procedure will be developed for each of the types of tests outlined in the foregoing paragraph 1.3.1.3.2. In certain cases, it may be advantageous to conduct certain steps of different procedures concurrently or subsequent to each other rather than during widely-separated phases of the test schedule. The scheduling of these steps will be accomplished at a later date.

1. Procedure for the evaluation of the system during normal operation

   All tests will be conducted at existing ambient conditions; no attempt will be made to simulate flight environments. Individual system components will be tested for proof pressure, leakage, and functional capability before installation in the test system.

   Before the system is filled with the fluid media, the test set-up will be checked to verify conformance with the system schematic, tightness of tubing connections, continuity in electrical systems, and adequacy of support for all components and plumbing. The fuel tanks and oxidizer tanks will be filled with water. The helium storage tank (and consequently the whole system) will be pressurized initially to 170 psig with nitrogen or helium. The system will be checked for leakage. The pressure in the helium tank will then be increased to 4500 psia. Initial pressure and temperature readings will be recorded, and the recording instruments will be started.

   The simulated rocket engine injector valves will be actuated, and the pressurized water will be fed through the system for 10 seconds. The recorded data and the test set-up will be checked for discrepancies; sufficient testing will be accomplished to verify satisfactory operation.

The system will then be subjected to 20 cycles of operation. Each cycle will consist of a 1-second period of energizing the injector valves and a following shutdown period of 10 seconds. The recorded data and system will be checked for discrepancies. Sufficient testing will be accomplished to verify satisfactory operation.

The injector valves will then be energized for periods of 20, 30, 40, 50, 60, and 68 seconds, respectively. If discrepancies in data arise during any of the foregoing tests, the individual test will be repeated until the problem has been defined and corrected.

2. Procedure for the evaluation of the system during off-limit operation

Upon satisfactory completion of the foregoing normal operation tests, the system will be subjected to a number of off-limit operation tests to determine the effects of off-design conditions on the over-all performance of the system. A few of the possible off-limit conditions are listed below:

a. Above-normal helium pressure - This condition can result from a second stage failure of either or both of the regulators. The regulator can fail OPEN, permit helium leakage by the seat, or provide a high outlet pressure because of a change in setting.

b. Below-normal helium pressure - This condition can result from a change in regulator setting or the introduction of a restriction in the feed lines.

c. Below-normal helium flow - This condition can result from any of the following components failing CLOSED: solenoid valve, regulator, or check valve. Similarly, any restriction in the line can result in below-normal helium flow.

d. Below-normal propellant flow - This condition can result from a failure of a propellant utilization valve or the introduction of a restriction in the feed lines.

Each of the conditions mentioned in the foregoing outline will be simulated during system testing. To thoroughly check the performance of the propellant system during these off-design conditions, the system will be tested as described below for each of the off-design conditions.

The system will be prepared for testing as previously described. The simulated rocket engine injector valves will be actuated, and the pressurized water will be fed through the system for 10 seconds. The recorded data will be checked, and the test will be repeated a minimum of three times. The system will then be subjected to 20 cycles of operation. Each cycle will consist of a 1-second period of energizing the injector valves and a following shutdown period of 10 seconds. After checking the data, the test will be repeated a second time. The injector valves will then be energized for 70 seconds. This test also will be repeated a second time after the recorded data.

Additional individual tests will be added to the program as system operating characteristics become known and as problems arise during the testing.

3. Procedure for the investigation of plumbing and component assembly techniques

The components are joined to plumbing, and plumbing details will be joined to each other by a method to be developed at the laboratory level. The method will be evaluated by assembling and disassembling joints while the components and plumbing are installed on the F-3 test fixture. The propellant system will have an estimated fifty individual assembly joints. Each joint will undergo at least one assembly and disassembly cycle. Selected joints will be assembled and disassembled as many as six times. The following procedure will be followed during an individual assembly and disassembly cycle:

a. The mating tube ends will be fabricated, cleaned, and inspected in accordance with methods previously developed during the laboratory tube-joint test program. Any weaknesses in the recommended methods will be reported, and improvements will be investigated.

b. Commercial or laboratory developed tools and fixtures will be employed to join the tube ends.

c. The joint will be subjected to a pressure of 1.5 times the operating pressure for 5 minutes at room temperature, using helium as the fluid. A visual inspection will be made for evidence of permanent deformation.

[redacted]

d. The joint will be subjected to operating pressure for 5 minutes, using helium as the fluid. Leakage will be measured by a mass spectrometer probe that will be calibrated before each day's use and have a minimum sensitivity of 10^{-9} st. cc he/sec. In addition, a leakage test at 50 psi and room temperature will be conducted for a period of 5 minutes on all mechanical fittings (other than brazed or welded) designed so that sealing is assisted by internal pressure.

e. Commercial or laboratory developed tools and fixtures will be employed to disassemble the joint.

f. The joint will be thorougly inspected to determine if the disassembly method contaminated the system or permanently damaged the joint ends.

1.3.1.3.3 Equipment Requirements. The equipment required to accomplish the objectives of the test program will include a test stand; pressure, temperature, and flow-sensing elements; indicating and recording equipment; and miscellaneous support equipment.

The test stand will be a structural steel framework to which are attached helium and propellant tanks constructed to ASME codes. Numerous off-the-shelf components that make up the pressurization and propellant distribution subsystems will be included. Propellant receiving tanks will be installed with solenoid valves that simulate the rocket engine injector valves. The propellant utilization subsystem will be designed and fabricated by a subcontractor.

A general list of the types of sensing elements, recording equipment, and miscellaneous equipment required for the test program follows:

1. Pressure transducers, 0 to 500 psig and 0 to 7500 psig
2. Liquid flow transducers, strain-gage type, 0 to 250 gpm
3. Thermocouple probes, stainless steel jacketed, 0 to 300 F
4. Modules, transducer range balance and calibration control, 0 to 15 v dc
5. Amplifiers, wide-band differential, dc-35 kc
6. Galvanometers, optical recording, dc-135 cps

7. Galvanometers, wide-band recording, dc-5 kc frequency response

8. Oscillators, time-base function generator, 0 to 1 kc

9. Oscillographs, direct-write recorder, 18 channels (maximum)

1.3.1.3.4 Facilities. A special test area will be prepared at the S&ID facility in Downey, California.

1.3.1.3.5 Test Schedule. The test schedule for the F-3 propellant system development tests is shown in Figure 1-3.

The combined test schedule for the F-1, F-2, and F-3 propellant system development test is shown in Figure 1-4.

1.3.1.4 Zero- and Low-Gravity Behavior and Management of SPS Propellant

1.3.1.4.1 Objectives. This test will experimentally determine the SPS propellant behavior during zero- and low-gravity portions of the Apollo mission. Test results will allow the proper design of propellant tankage and programming of mission maneuvers (such as propellant settling, vehicle rotation reorientations) for optimum system performance. The conditions under which liquid propellant is displaced from the bottom of the tank will be established. Using this information, it may be possible to predict the location of the propellant during various phases of the mission. Propellant management systems such as anti-geysering baffles and propellant retention screens will have their design parameters based on this test. The effects of low-gravity propellant dynamics (geysering, sloshing) on vehicle motion and stability also will be established.

1.3.1.4.2 Test Program.

1. Zero-g settling. A drop tower facility at S&ID, Downey, and, possibly, the experimental X-15 aircraft will be used in these tests. Transparent plexiglass models 1.32 and 2.64 inches in diameter will simulate the fuel tank and models 1.50 and 3 inches in diameter will simulate the oxidizer tank. These models will be subjected to accelerations of from 0.01 to 0.1 g during a free fall in the drop tower. Test duration will be approximately 1 to 1.5 seconds. In the X-15 test, the settling accelerations cannot be completely controlled but will vary with the trajectory and drag of the aircraft. Tests in the aircraft will use a long thin capillary tube to permit study of the transient phases of settling.

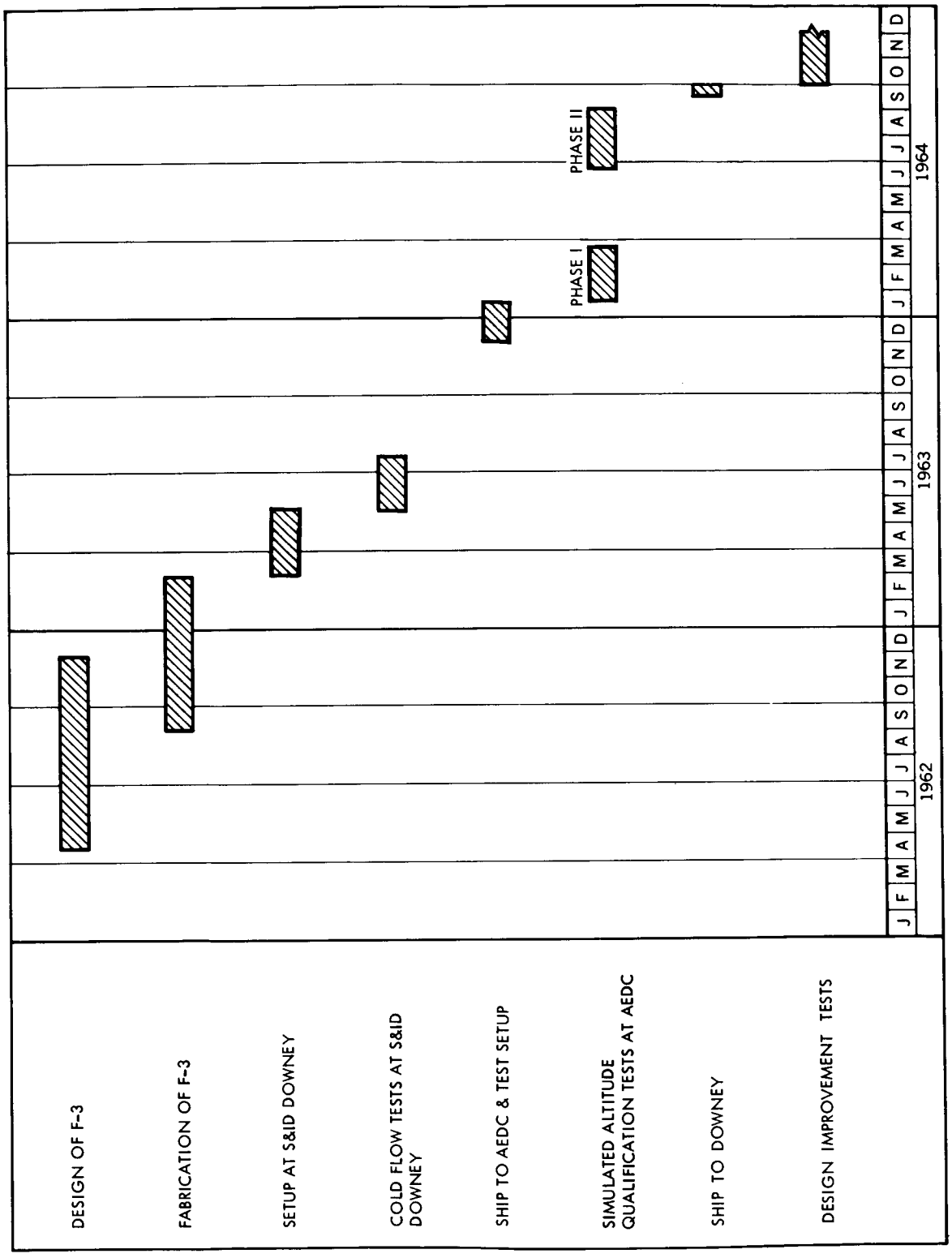

Figure 1-3. F-3 Test Fixture Test Schedule

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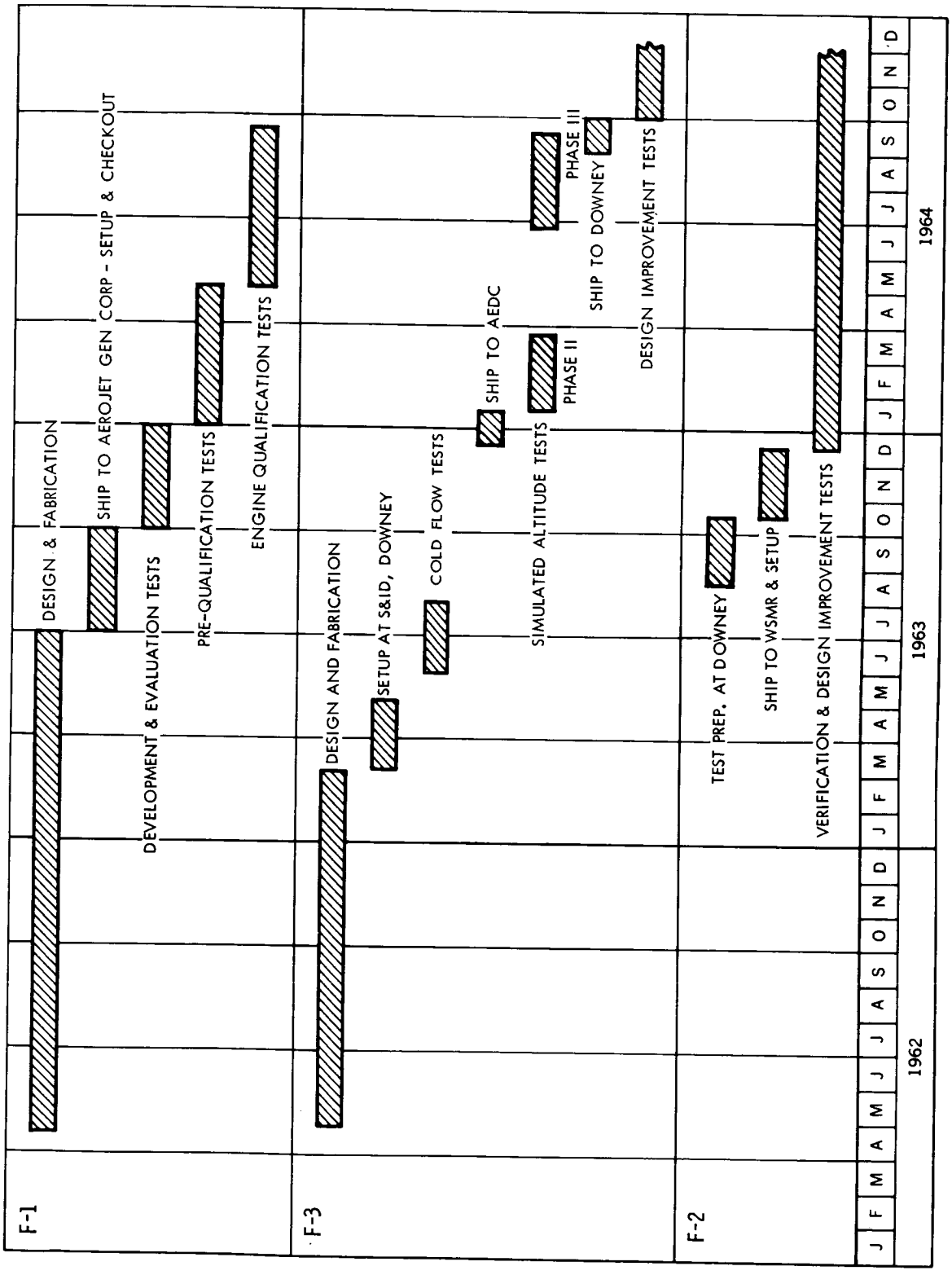

Figure 1-4. F-1, F-2, and F-3 Test Fixtures Combined Schedule

[redacted]

By use of the large scale centrifuge at Edwards Air Force Base, the settling correlations will be extended to high-g conditions of 10 g's or more.

2. Propellant geysering. Propellant geysering, Figure 1-5, will be evaluated under the range of conditions encountered in the Apollo mission. This study will be performed at 1 g using a 1/4-scale and a 1/2-scale plexiglass transparent tank in which the propellant Reynolds number is simulated. The liquid will be introduced at the top of the tank from a reservoir by way of a directional nozzle. Various baffling arrangements to prevent geysering will be studied. These tests will be performed in the S&ID Engineering Development Laboratory (EDL).

3. Vehicle maneuvers. The Lewis Research Center drop tower will be used to evaluate SPS propellant behavior during and after vehicle maneuvers. Both angular and translational accelerations will be applied to the model while it is in free fall. A camera, included as an integral part of the test package, will photograph the behavior of the liquid.

   A separate test package will be used in the KC-135 flying zero-g laboratory operated by Wright-Patterson Air Force base. RCS maneuvers also will be simulated in these tests. Because of the longer period of zero-g in the KC-135, larger models will be used. Large models also minimize the surface tension effects on propellant sloshing.

   These two tests also will serve as a comparison for the model scaling factors.

4. Retention devices. Several tests are required to demonstrate the effectiveness and reliability of a screen-type liquid retention device. The present considered design is a dense screen that works by the bubble pressure principle. Due to a disturbance, the liquid hydrostatic head is balanced (supported) by the pressure drop required to force a bubble through the screen. The smaller the screen pore size the greater the bubble pressure and the greater the ability to retain liquid.

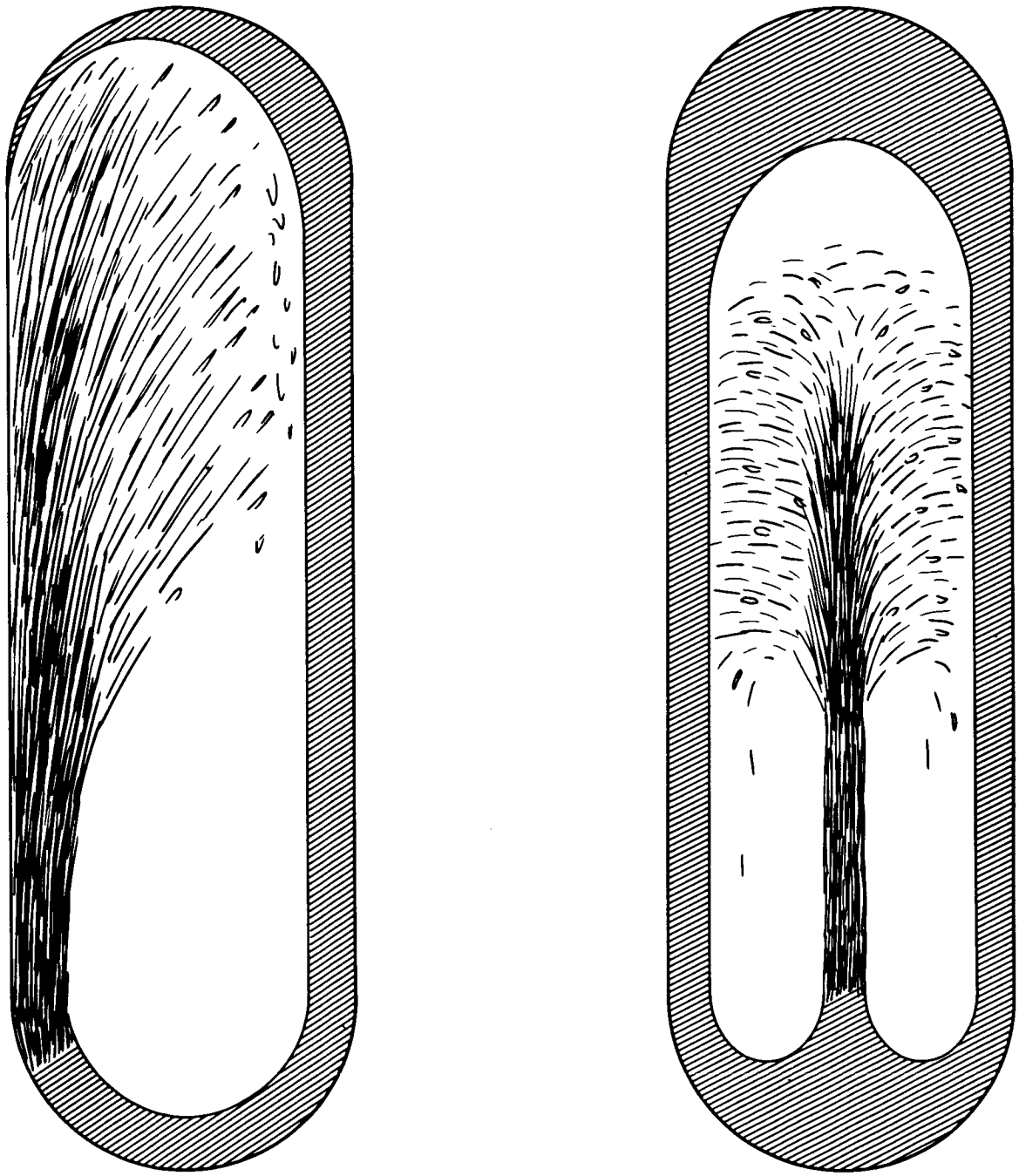

Figure 1-5. Propellant Geysering During Settling Maneuver

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For testing, the cylindrically shaped screen will be submerged in water, and a gas feed device within the screen device will be pressurized until the first bubble appears. The screen must also be dynamically tested to show its resistance to engine firing and docking jolts. This involves testing the screen device at the maximum possible disturbance acceleration. In addition, the compatibility of the screen with the propellants will be determined over at least a two-week period. Screen flow and clogging characteristics under operating conditions will be studied in a full-scale facility. All tests will be performed at S&ID EDL.

6. Vapor ingestion. Gas tends to pull into the feedout line during low-gravity SPS engine starts, prior to complete draining of the propellant tank (see Figure 1-6). The conditions under which this pull through occur will be experimentally determined. Tests will be conducted under standard gravitational conditions, with the results related to actual conditions. Very small scale models, 1/12 scale and smaller, will be tested with very high outlet velocities to simulate the SPS Froude' number—a ratio of inertial forces to gravitational forces. These tests will be conducted at S&ID EDL.

1.3.1.4.3 Equipment. Equipment for all tests performed at EDL will be fabricated there. Equipment for tests to be performed at remote facilities will be self-contained and pretested before shipment to the test location by EDL. No extensive development effort is anticipated in the design of equipment, and where possible, equipment and/or design will be interchanged between tests.

1.3.1.4.4 Facilities. Tests will be performed at the following facilities.

1. S&ID, Engineering Development Laboratories, Downey
   a. Fabrication of test equipment
   b. Vapor ingestion tests
   c. Propellant geysering tests
   d. Retention device development and evaluation
2. Wright-Patterson Air Force Base, Ohio - KC-135 Flying Zero-g Laboratory
   a. Simulation of RCS maneuvers in zero-g environment

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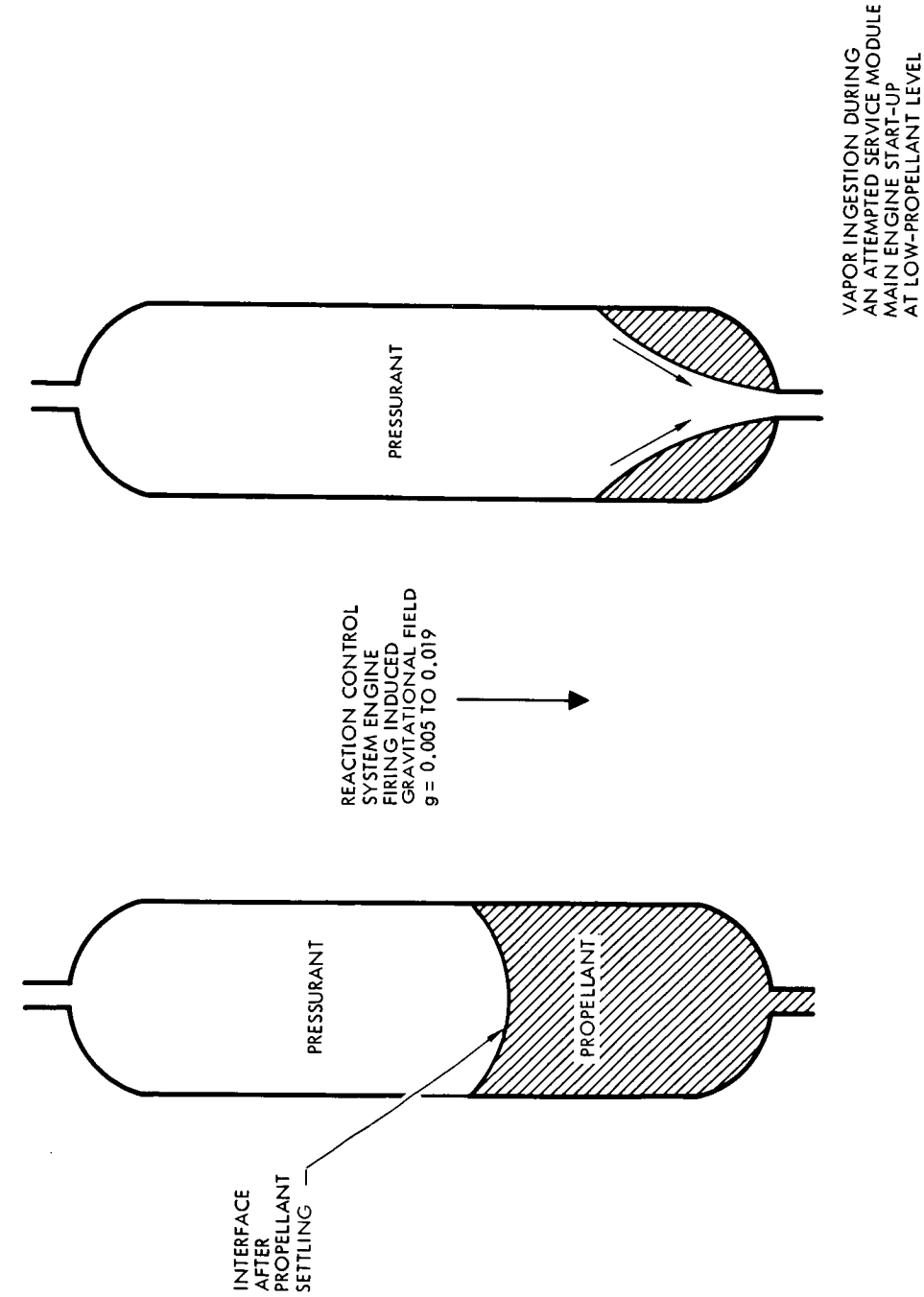

Figure 1-6. Propellant Settling and Vapor Ingestion

3. NASA, Lewis Research Center, Cleveland, Ohio - Zero-g Drop Tower Facility

   a. Propellant settling tests under low gravitational field

   b. Simulation of RCS maneuvers in zero-g environment

4. Edwards Air Force Base, California - NASA X-15 Manned Spacecraft

   a. Propellant settling under low gravitational field.

5. Edwards Air Force Base, California - Large Diameter Centrifuge Facility

   a. Propellant settling under high gravitational field

1.3.1.4.5 Test Schedule. Test schedule is shown in Figure 1-7.

1.3.1.5 S/M Ullage Transient Pressures

1.3.1.5.1 Objectives. These tests will determine the magnitude of heat transfer to the ullage and the effect of heat transfer on ullage transient pressures. To meet these objectives, the following will be accomplished.

1. The pressure and temperature history in the helium bottle during blowdown and/or bottle charging period will be determined to verify the analytic bottle blowdown and consumption predictions.

2. The helium bubbling method of heat exchange will be evaluated, and the test data will be compared with analytic predictions. Specific items that will be determined are:

   a. The development of bubble cap

   b. The magnitude of propellant solidification in standpipe when bubbling cold helium.

3. The performance of the helium heat exchanger in the fuel and oxidizer lines will be evaluated to verify analytic predictions. Any solid formation on the exchanger coil will be observed visually, and the results will be correlated with inlet helium temperature.

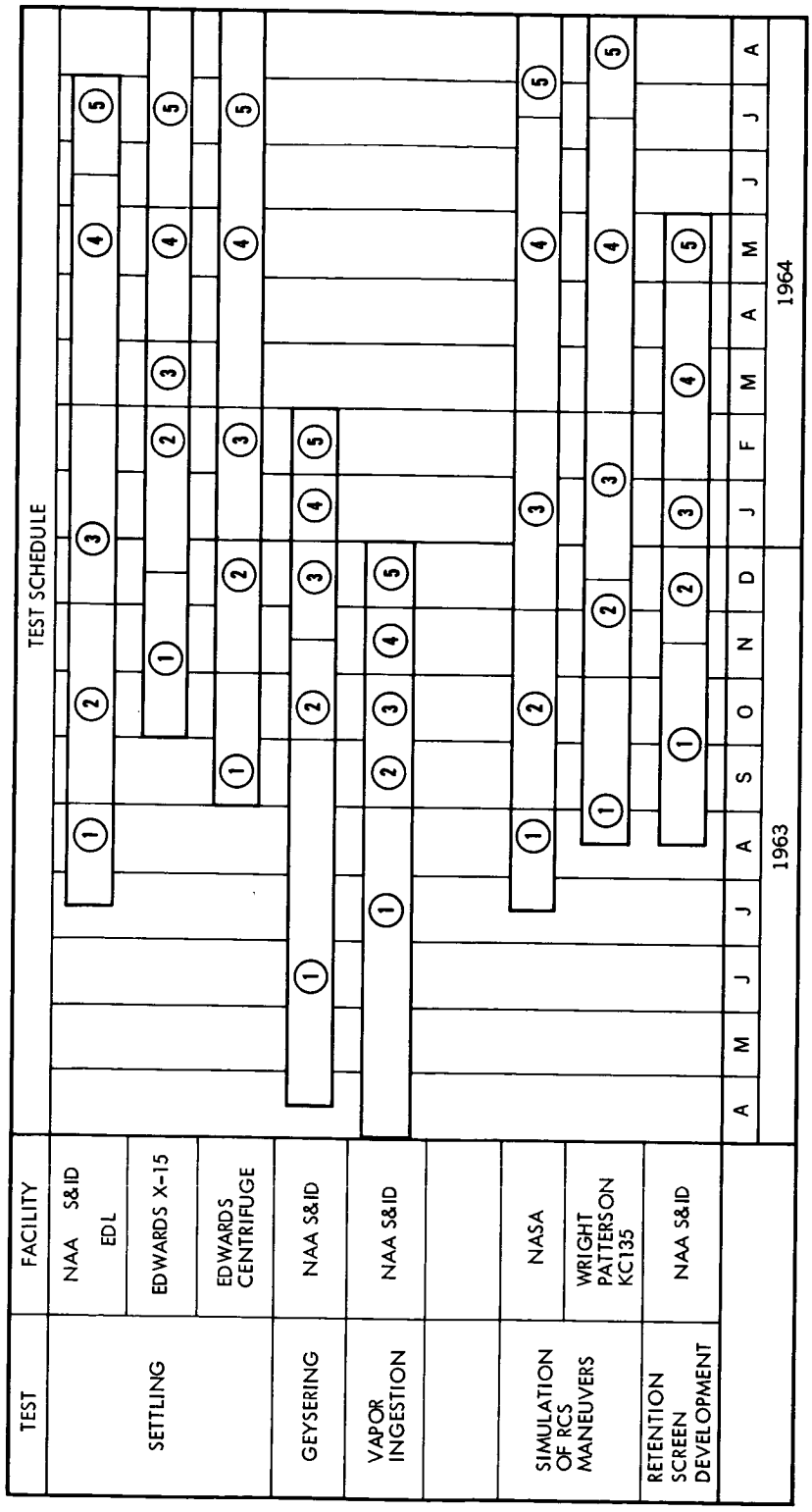

Figure 1-7. Zero- and Low-Gravity Test Schedule

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4. The temperature and pressure time history of the ullage gas in a N_2O_4 tank during ullage blowdown will be determined.

1.3.1.5.2 Test Plan.

1. Helium bottle blowdown and helium bubbling. The helium bottle blowdown and the helium bubbling test is conducted using the setup shown in Figure 1-8. The following test procedure is used.

   a. Pressurize the helium bottle from a helium supply source to 4000 psia.

   b. Replenish the supply until the temperature in the bottle reaches ambient.

   c. Initiate blowdown at a rate comparable to S/M consumption.

   d. Record data shortly before blowdown, during entire blowdown period, and for a time after blowdown.

   e. Observe visually and/or photographically the required data.

2. Propellant heat exchanger. The test of the propellant heat exchanger uses the setup shown in Figure 1-9. Tests are conducted over a range of propellant and helium flow rates and temperatures to verify heat exchanger analysis.

3. Ullage blowdown. The test of ullage blowdown uses the test setup shown in Figure 1-10. The following test procedure is used.

   a. Purge the tank and system and partially fill it with N_2O_4, pressurized to each specified test pressure (P_1) with gaseous helium.

   b. Agitate to assure saturation of the helium with the N_2O_4 vapor.

   c. Regulate the flow using the flow orifice (scale the flow according to the quantity of propellant being used).

1.3.1.5.3 Equipment.

1. The following hardware items are required for these tests.

   a. Helium storage bottle (full size or thermally similar model)

   b. Helium fill and vent valve

c. Helium supply and service facilities (procured or leased)

d. Helium regulator

e. Helium check valve

f. Propellant tank or scale model

g. Various helium diffusers

h. Low-pressure fuel to helium heat exchanger (lucite exchanger shell)

2. The following instrumentation and recording equipment are required for the tests.

a. Helium bottle pressure transducer

b. Helium bottle temperature thermocouple

c. Helium bottle wall temperature thermocouple

d. Helium temperature thermocouple downstream of pressure regulator

e. Helium flow meter

f. Ullage helium pressure transducer

g. Ullage helium temperature thermocouple

h. Propellant flowmeter

i. Helium Δp pressure transducer and Δt sensor across heat exchanger

j. Fuel Δp pressure transducer and Δt sensor across heat exchanger

k. Insulation wall temperature thermocouple

l. Vacuum pressure and temperature indicator

m. Multi-channel high-speed oscillographs

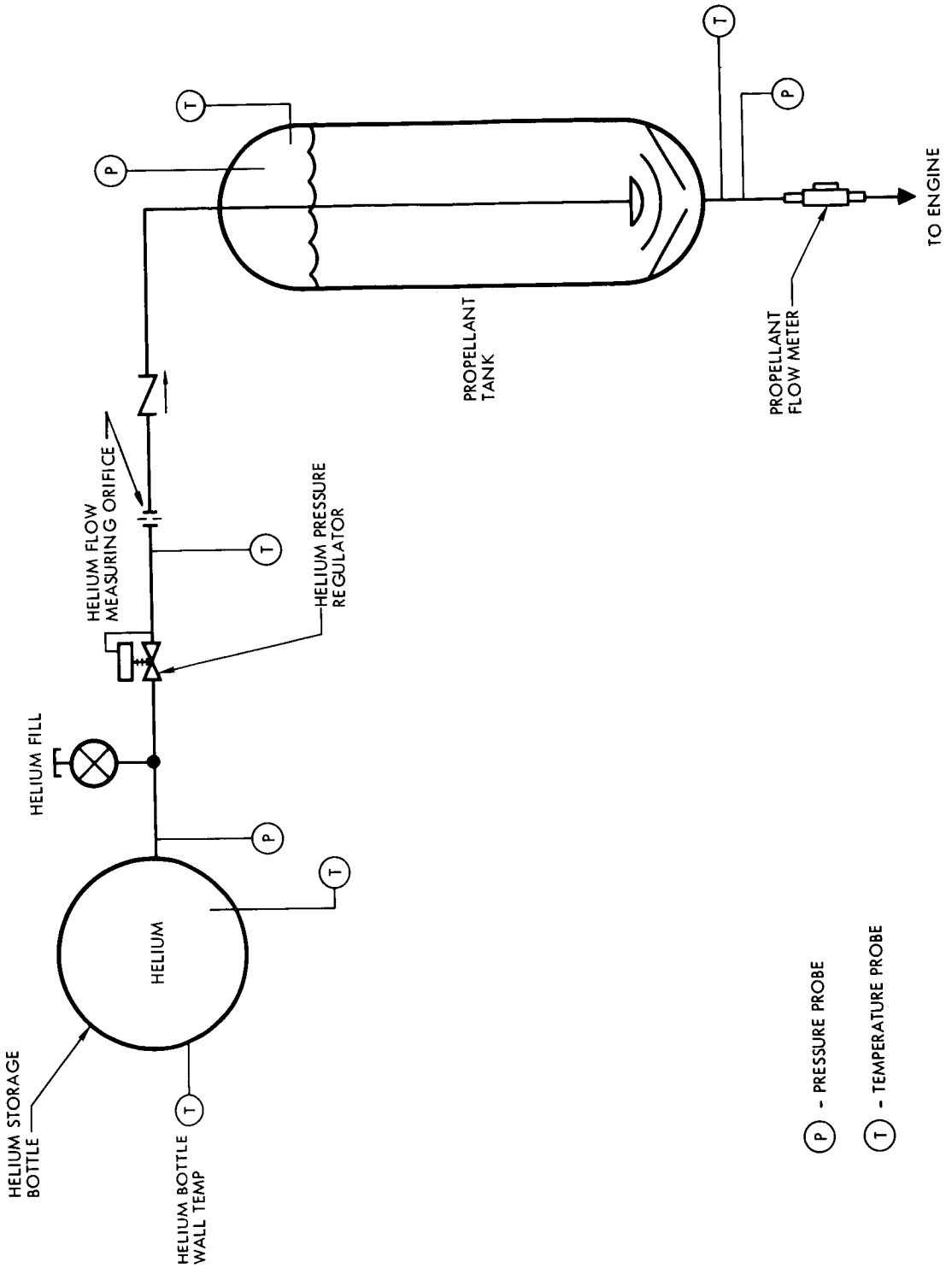

Figure 1-8. Helium Bubbling Heat Exchanger

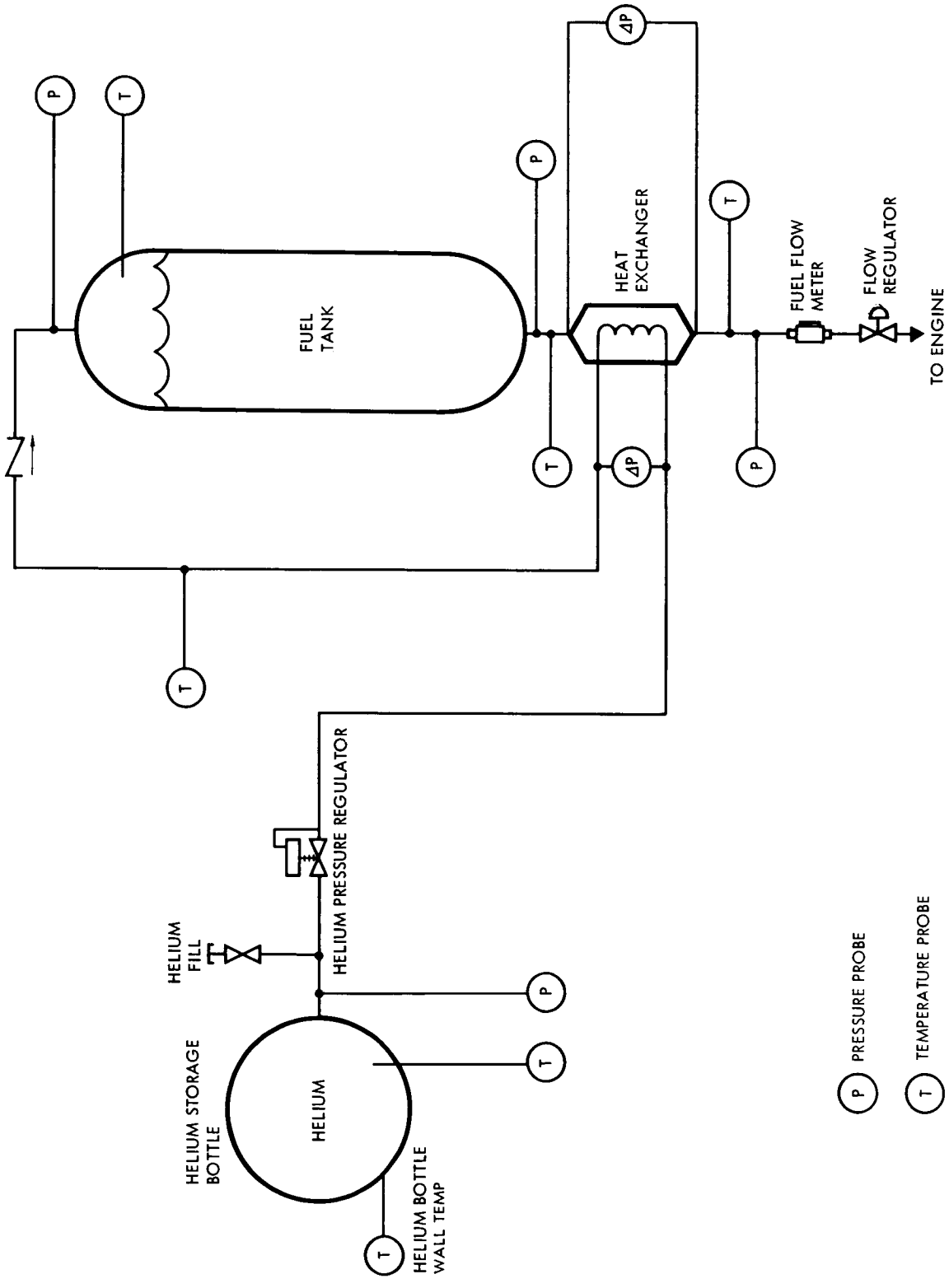

Figure 1-9. Helium-Fuel Heat Exchanger

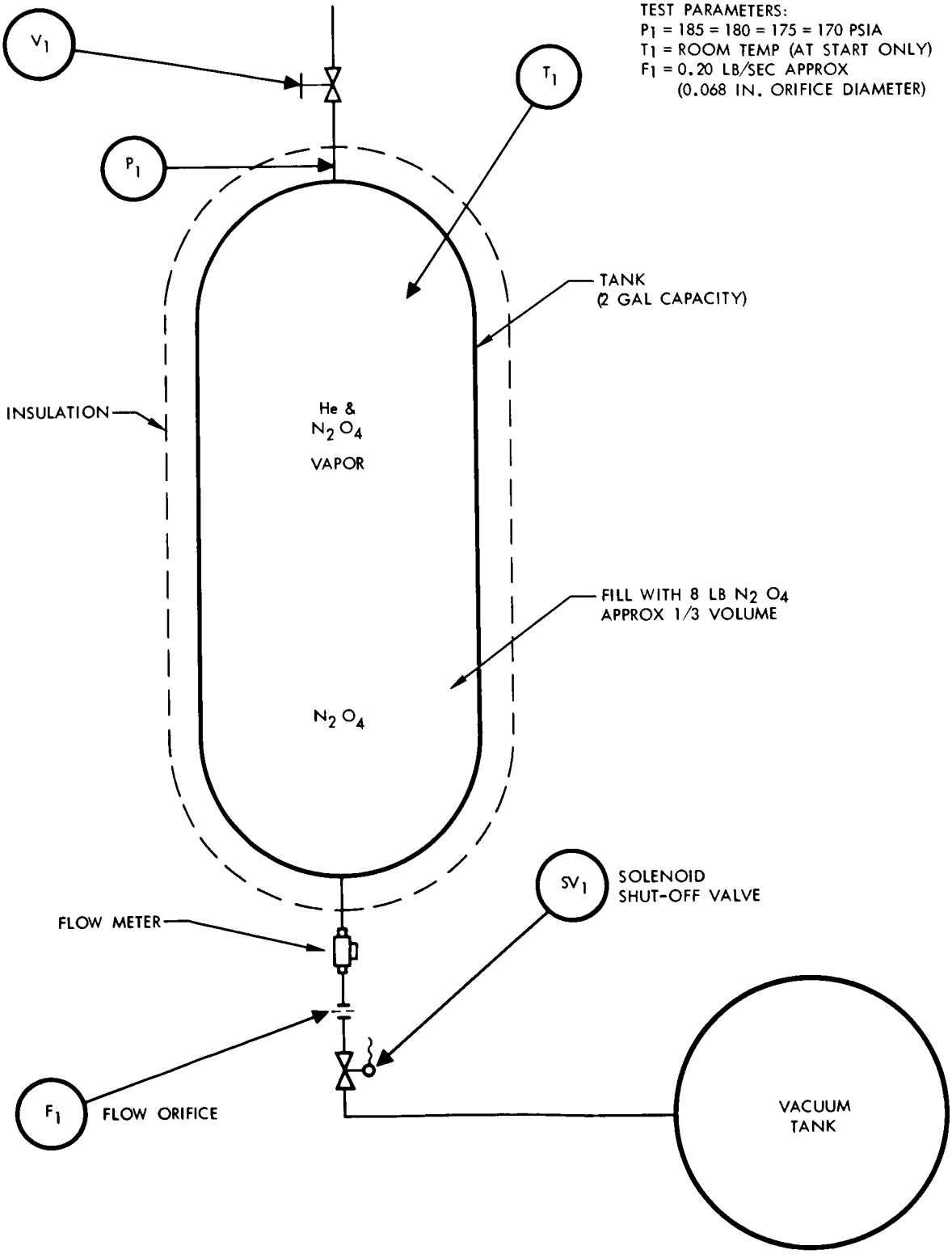

Figure 1-10. Service Module Ullage Test Configuration

1.3.1.5.4 Facilities. Most of the components used in the test will be procured as off-the-shelf items that have already met government specifications. Other components will be developed by the S&ID EDL. Standard test facilities available in S&ID EDL will be supplemented by a helium supply truck, recording equipment, and auxiliary equipment.

1.3.1.5.5 Test Schedule. The test schedule is presented in Figure 1-11.

1.3.1.6 Surface Heating and Pressure Effects Tests

1.3.1.6.1 Objectives. This test will be used to accomplish the following:

1. Simulate SM/RCS rocket plume interaction with service module surface.
2. Define the pressure.
3. Define the pressure and heat transfer distribution on a flatplate surface immersed in the exhaust plume at simulated space conditions.
4. Obtain correlation between theoretical analyses and test results.
5. Define a satisfactory location for the SM/RCS, with or without plume deflectors, considering surface heating and side thrust.
6. Demonstrate the operation of the integrated RCS at the maximum obtainable altitude environment.
7. Obtain data on the effect of the RCS plume impingement on samples of the actual radiator surface.

1.3.1.6.2 Test Plan. The test plan consists of three phases.

1. Phase I test activity will consist of a checkout of vacuum cell capability with the operation of a rocket engine using hypergolic propellants, feasibility study of techniques for flow-field and shock visualization, and qualification of plate pressure and temperature instrumentation.
2. Phase II testing will consist of a parameteric study of the surface-heating rate and pressure distribution at various nozzle cant angles and nozzle heights above the test plate, a study of the

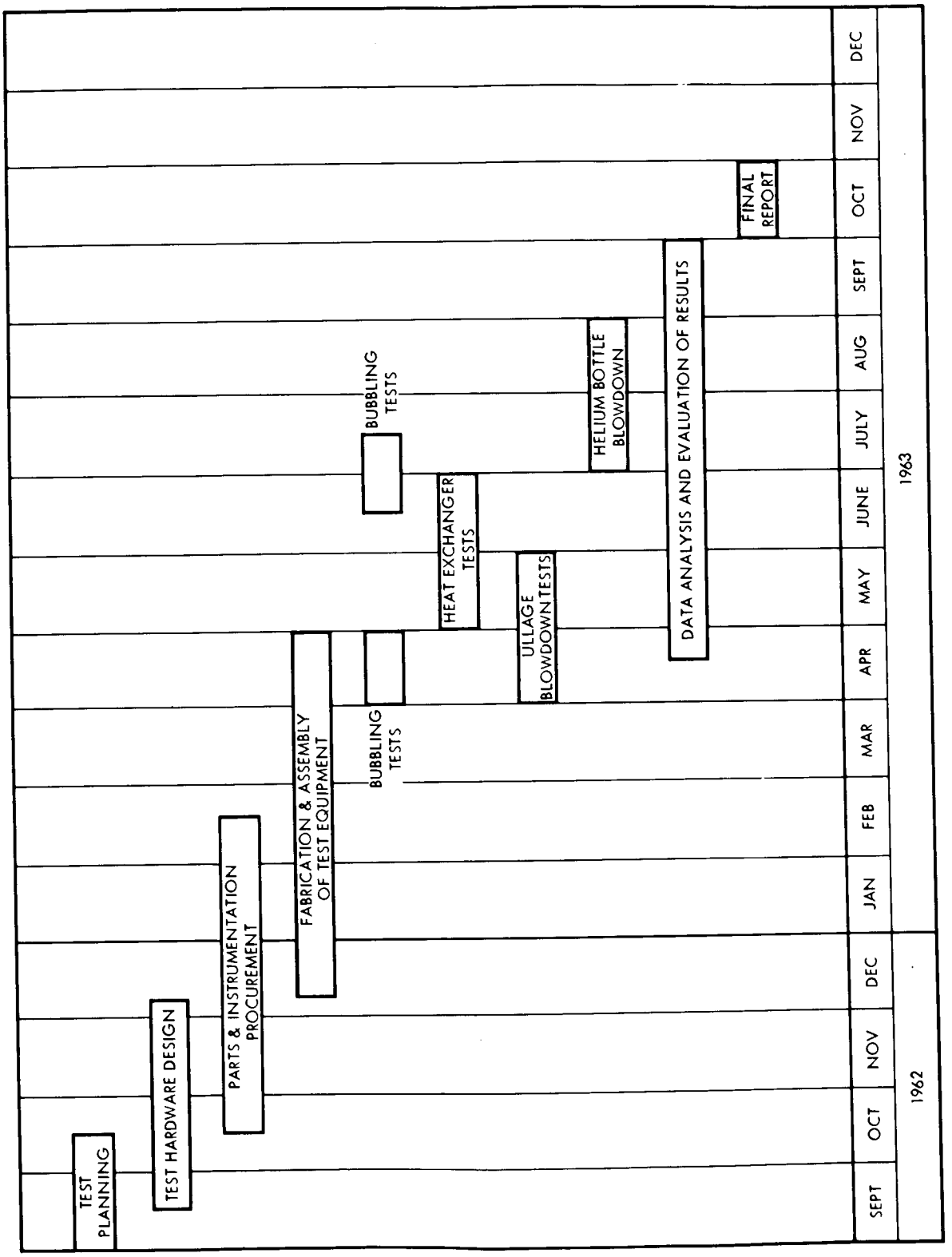

Figure 1-11. Service Module Ullage Transience Test Schedule

effect on surface heating and pressure and deflector designs, and a study of the effect of exhaust plume impingement on the radiatior surface.

3. Phase III testing will study the operating characteristics of the integrated RCS at the maximum available altitude and the effect of the radiation reflector on the rocket motor life.

1.3.1.6.2.1 Test Requirements. The RCS space exhaust plume will be simulated at available vacuum cell conditions by reducing the area ratio of the nozzle to the point where the initial inclination angle of the flow issuing from the exit equals that in space. To determine the effect of reducing the area ratio, several area ratio-vacuum cell conditions will be tested. The degree of simulation will be checked with flow-field and shock-pattern visualization techniques.

The integrated RCS will be tested for thrust build-up and ignition characteristics, engine life, and complete system operation at maximum available altitudes.

1.3.1.6.2.2 Data Requirements.

1. Surface temperature versus time

2. Surface static pressure versus time

3. Flow-field and shock-pattern visualization

4. Radiator sample temperature, absorptivity, emissivity, and surface mechanical condition versus time

5. Rocket engine: Pc, Wf, Wo, Pinj, P tank, thrust, total running time

1.3.1.6.2.3 Data Reduction.

1. Pressure and temperature distribution for various area ratios, nozzle-to-plate distances, and cant angles

2. Test-plate heat transfer distribution for various area ratios, nozzle-to-plate distances, and cant angles

1.3.1.6.2.4 Analysis. The test-plate heat transfer and pressure data will be analyzed to develop correlation between test data and theoretical analysis. The flow visualization will be used to determine the degree of shape simulation to correlate test configurations.

[redacted]

1.3.1.6.3 Equipment. The following equipment will be required.

a. Rocket motors with four different area ratio nozzles (10, 15, 20, 40) and propulsion support system (heavy hardware and integrated RCS system), flat-plate instrument surface, radiator samples, and deflector

b. Heat transfer instrumentation capable of 1.0 to 26.0 Btu/ft/sec and high response, pressure instrumentation capable of 1.0 psia and high response

c. Equipment for testing optical properties of radiator surface coatings after exposure during RCS test

1.3.1.6.4 Facilities. The J2A Test Cell at AEDC, Tullahoma, Tennessee, will be used to achieve the desired test conditions. The capability of the cell is expected to be at least 300,000 ft.

1.3.1.6.5 Schedule. Figure 1-12 presents the schedule for surface heating and pressure effects tests.

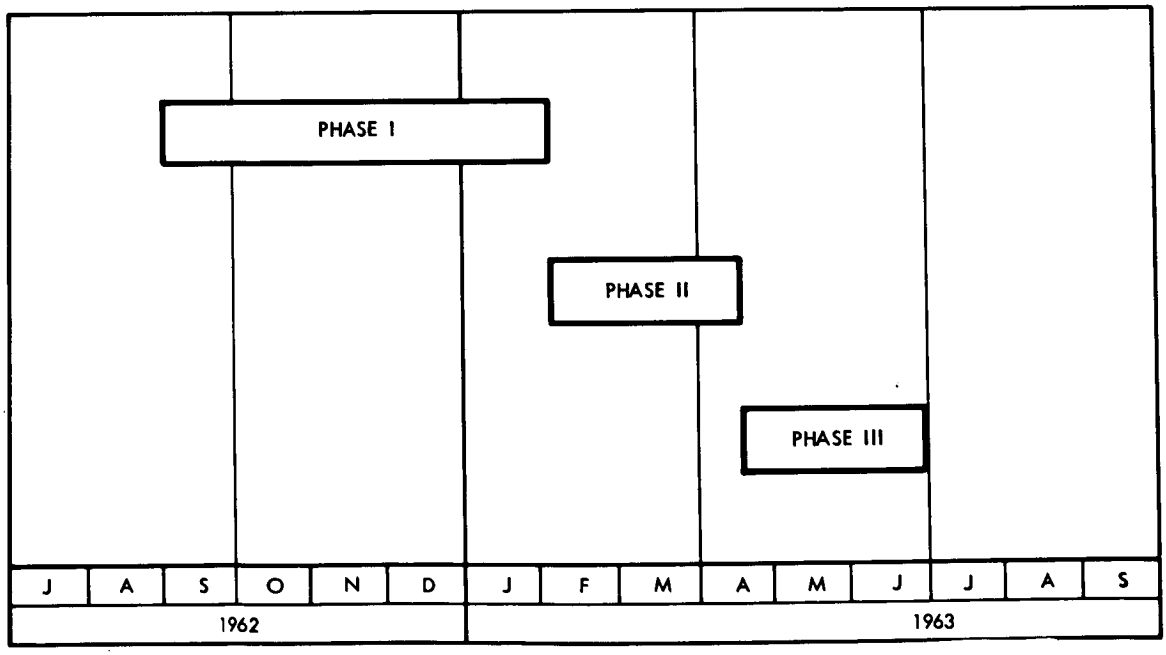

Figure 1-12. Test Schedule for Surface Heating and Pressure Effects Test

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2.0 REACTION CONTROL SYSTEM

2.1 SCOPE

The RCS for the command module and service module development program will include engineering development, evaluation, and design verification tests conducted by the subcontractor and S&ID. Qualification tests will be conducted in accordance with procedures described in SID 62-109-3. The subcontractor development test program consists of experimental tests and prototype development tests. The development tests program of S&ID consists of different phases of tests at the breadboard level to determine subsystem compatibility, to verify component supplier's test results, and to evaluate the system before the integrated system tests.

2.2 SUBCONTRACTOR TEST PLAN

2.2.1 Marquardt Test Plan

2.2.1.1 Objective

The primary objective of the subcontractor's test plan is to develop and verify the design configuration of the Apollo spacecraft reaction control system. This objective will be accomplished by developing the system in a logical sequence and will culminate in a final design capable of meeting the high standards of reliability required for Apollo spacecraft.

2.2.1.2 Test Plan

The development test plan is divided into two major phases of development and design verification testing: experimental tests and prototype development tests.

2.2.1.2.1 Experimental Test Plan. The purpose of the experimental test plan is to establish the detail design criteria for the prototype design and to determine the optimum component configuration.

Various injectors will be investigated and tested to determine the optimum configuration compatible with short-pulse performance, steady-state performance, and engine-life considerations.

Tests will be conducted to establish the optimum combustion chamber geometry with consideration of life and performance requirements. This

[redacted]

program will include developmental investigations to determine the minimum practical chamber weight that will result in a low-heat capacity chamber and thus reduce the required heat sink capacity of the injector head at engine shutdown.

2.2.1.2.2 Prototype Development Test Plan. This test plan will include minimum-impulse performance tests, life tests, and environmental tests on individual components and/or the complete prototype engine. The results of these tests will probably precipitate design modifications. The final design will then be recycled through the development test program.

2.2.1.2.2.1 Thrust Chambers. Material evaluation (sea level and altitude) and coating evaluation (sea level and altitude) tests will be conducted on the thrust chambers.

2.2.1.2.2.2 Propellant Solenoid Valves. The following tests will be conducted on the injector solenoid valves.

1. Steady-state tests, including flow versus pressure drop across the valve, and leakage and proof-pressure tests
2. Dynamic response tests matching opening and closing time, using minimum and maximum voltage
3. Cycling test (minimum of 100,000 cycles at heat-soak temperatures)
4. Temperature extremes (to specification), excluding those conditions in cycling tests
5. Vibration tests
6. Vacuum and propellant soak tests
7. Radio interference tests
8. Explosive atmosphere tests
9. Burst-pressure tests

2.2.1.2.2.3 Injector Heads. The following tests will be conducted on the injector heads.

1. Pressure tests, including leakage and proof-pressure tests
2. Flow tests of fuel and oxidizer throughout the flow and differential pressure range

3. Total flow tests determining proper spray distribution

4. Spray-impingement tests determining proper spray impingement and no excessive breakthrough of either oxidizer or fuel streams

5. Burst-pressure tests

2.2.1.2.2.4 Rocket Engine Tests. Rocket engine tests will include the following:

1. Nominal steady-state and minimum-impulse performance, i.e., thrust, efficiency, propellant flow, nominal oxidizer-to-fuel ratio (O/F) and off O/F ratios

2. Reliable life tests (sea level and altitude) with mission cycle tests, including temperature and heat soak-back and test to failure

3. Attitude tests, vertical upward, and horizontal tests will be conducted and compared to vertical downward tests. These tests will include starts, repetitive starts, minimum impulse, and steady-state performance.

4. Pulse-modulation tests

5. Supply pressure variation tests including propellant depletion tests

6. Limited environmental tests

7. Burst-pressure tests

2.2.1.3 Equipment

The test facility will be equipped with remote controls, environmental simulation equipment, thrust measuring equipment, and ultra-high response recording and measuring instruments.

2.2.1.4 Facilities

The development tests of the S/M reaction control engines will be performed at Marquardt Jet Laboratory in Van Nuys, California. The test facility is equipped to run sea-level and altitude simulation tests. Chambers will be located at the test facility to produce altitude pressure simulation of 10^{-5} mm Hg for 100-millisecond runs and 0.02 psia for continuous runs.

2.2.1.5 Subcontractor Test Schedule

The subcontractor test schedule is shown in Figure 2-1.

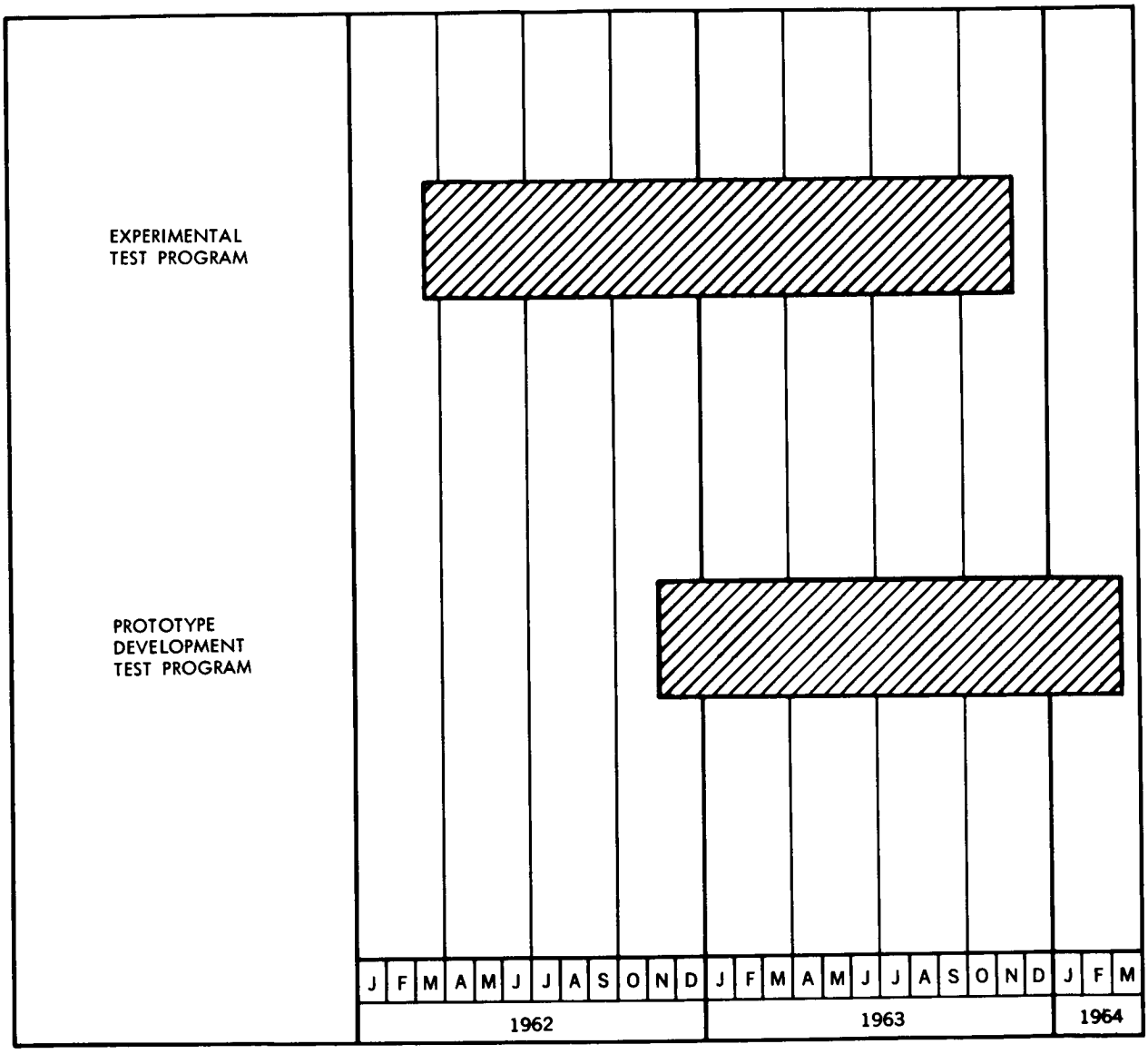

Figure 2-1. Reaction Control System Subcontractor (Marquardt) Test Schedule

2.2.2 Rocketdyne Test Plan

2.2.2.1 Objective

The primary objective of the subcontractors test plan is to verify the design configuration of the Apollo command module reaction control engines in compliance with the requirements of S&ID Procurement Specification MC-901-0067A.

2.2.2.2 Test Plan

Development of the Apollo command module RCS engines will be based on the Gemini 100-pound thrust orbit attitude and maneuvering system (OAMS) reaction control engines. The development test program is divided into two phases: experimental tests and prototype development tests.

2.2.2.2.1 Experimental Test Plan. The experimental portion of the plan, conducted concurrently with the prototype test plan, will be used to fabricate and test preliminary and backup designs. Various propellant valve problems, such as corrosion, leakage, response time, and excessive pressure losses in the internal passages, will be investigated during the experimental test program.

Thrust chamber heat transfer, char rate, performance characteristics, and endurance testing will be investigated. Assembly techniques and materials providing superior performance while maintaining minimum weight will be determined.

2.2.2.2.2 Prototype Development Test Plan. The prototype development test plan has been initiated with pulse-type tests, which have been demonstrated to be more detrimental on ablative chambers.

2.2.2.2.2.1 Thrust Chambers. Material evaluation and effect of operating and environmental conditions on thrust chamber life, heat transfer rates, and char rates are currently being tested.

2.2.2.2.2.2 Injector Solenoid Valves. Tests are being conducted to determine proof pressure, leakage, water calibration, insulation resistance, dielectric strength, coil resistance, power consumption, response time, and endurance (cycling) under sea level and altitude conditions.

2.2.2.2.2.3 Rocket Engine Tests. Rocket engine tests will include the following:

1. Engine durability will be demonstrated through a series of mission cycle tests. Particular attention will be given to adequacy of ablative wall thickness with respect to char depth and maximum sock-back temperature.

2. Engine performance will be demonstrated at rated and off-nominal conditions.

[redacted]

3. Engine operating-characteristics testing will define the start, restart, and cutoff transients under pulsing conditions. Minimum impulse bit characteristics will be obtained.

4. Engine heat transfer as a function of pulse length and run time will be determined.

5. Actual safe operating limits of the engine system will be determined by overstress testing. Minimum and maximum safe operating points of temperatures, pressures, thrust, mixture ratio, engine voltage, shocks, vibration, and corrosion will be demonstrated.

6. Malfunction simulation testing will demonstrate the ability of the engine to complete the mission safely in the event of a malfunction, such as off-mixture ratio, excessive propellant inlet pressures, and excessive propellant and hardware temperatures.

2.2.2.3 Equipment

The test facility will be equipped with remote controls, environmental simulation equipment, thrust measuring equipment, and ultra-high response recording and measuring instruments.

2.2.2.4 Facilities

The development of the command module reaction control engines will be accomplished at the Rocketdyne Canoga Plant Development Laboratory and the Rocketdyne Propulsion Field Laboratory. Facilities to conduct component environmental tests are located in the Development Laboratory. The Propulsion Field Laboratory has facilities equipped to fire the engines at both sea level and altitude. The altitude environment capability is 100,000 feet and 200 F.

2.2.2.5 Subcontractor Test Schedule

The Rocketdyne test schedule is shown in Figure 2-2.

2.3 S&ID TESTS

2.3.1 Breadboard Testing of Apollo Command Module RCS

2.3.1.1 Objectives

The breadboard testing of command module reaction control system will accomplish the following objectives:

1. Provide experimental evaluation of the integrated system
2. Prove design concepts

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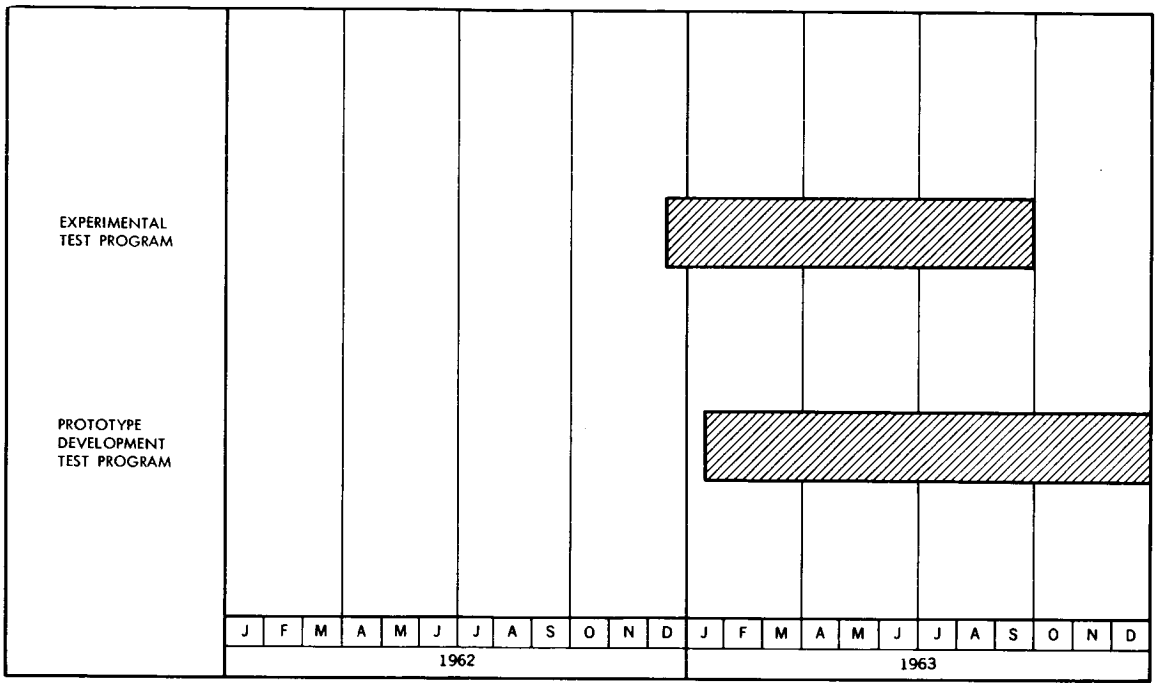


Figure 2-2. Reaction Control System Subcontractor (Rocketdyne) Test Schedule

3. Resolve design difficulties

4. Ensure compatibility of components

5. Provide data for system calibration

6. Resolve propellant handling techniques

7. Verify the suitability of the system for its ultimate use

2.3.1.2 Test Plan

The testing of the breadboard system will be divided into three progressive phases. The major differences in the test phases will be in the types of components used in the test setups and in the fluid media used during the test runs. Phase I testing will employ available off-the-shelf components that will fulfill the preliminary design requirements. The fluid media to be used during Phase I will be water and nitrogen.

[redacted]

Phase II components will be flight articles that satisfy the requirements of S&ID equipment specifications but which have not completed qualification testing. Phase III components will be fully-qualified flight articles. The fluid media to be used during Phase II and Phase III testing will initially be distilled water and will ultimately be hypergolic propellants.

2.3.1.2.1 Data Requirements. During the testing of the command module RCS, the following list will be monitored and recorded:

1. Pressure of gas in helium tank
2. Temperature of gas in helium tank
3. Inlet pressure of regulator No. 1
4. Inlet pressure of regulator No. 2
5. Outlet pressure of the primary stage of regulator No. 1
6. Outlet pressure of the primary stage of regulator No. 2
7. Outlet pressure of the secondary stage of regulator No. 1
8. Outlet pressure of the secondary stage of regulator No. 2
9. Inlet pressure of the check valves
10. Pressure of gas in fuel tank on gas side of bladder
11. Temperature of gas in fuel tank on gas side of bladder
12. Pressure of fuel in fuel tank on fuel side of bladder
13. Temperature of fuel in fuel tank on fuel side of bladder
14. Pressure of gas in oxidizer tank on gas side of bladder
15. Temperature of gas in oxidizer tank on gas side of bladder
16. Pressure of oxidizer in oxidizer tank on oxidizer side of bladder
17. Temperature of oxidizer in oxidizer tank on oxidizer side of bladder

18. Inlet pressure of the oxidizer burst disc
19. Inlet pressure of the fuel burst disc
20. Outlet pressure of the fuel solenoid valve
21. Outlet pressure of the oxidizer solenoid valve
22. Flow rate of oxidizer
23. Flow rate of fuel
24. Engine +P fuel line temperature
25. Engine +P fuel line pressure
26. Engine +P oxidizer line temperature
27. Engine +P oxidizer line pressure
28. Engine -P fuel line temperature
29. Engine -P fuel line pressure
30. Engine -P oxidizer line temperature
31. Engine -P oxidizer line pressure
32. Engine +Y fuel line temperature
33. Engine +Y fuel line pressure
34. Engine +Y oxidizer line temperature
35. Engine +Y oxidizer line pressure
36. Engine -Y fuel line temperature
37. Engine -Y fuel line pressure
38. Engine -Y oxidizer line temperature
39. Engine -Y oxidizer line pressure
40. Engine +R fuel line temperature

41. Engine +R fuel line pressure

42. Engine +R oxidizer line temperature

43. Engine +R oxidizer line pressure

44. Engine -R fuel line temperature

45. Engine -R fuel line pressure

46. Engine -R oxidizer line temperature

47. Engine -R oxidizer line pressure

2.3.1.2.2 Test Procedures. The command module reaction control system will consist of two independent systems. The systems will be identified as system A and system B. Both systems will be installed on the test stand to expedite the test program. Off-the-shelf components will be installed on system A for Phase I testing. Components that meet S&ID specifications but have not been qualified will be installed on system B for Phase II testing. During Phase II testing, system A will be reworked to incorporate qualified components for Phase III testing. At the conclusion of Phase II testing, system B will be reworked to incorporate qualified components for Phase III testing. The two systems will be tested during Phase III.

The tests will be conducted at existing ambient conditions of pressure and temperature, with no attempt to simulate flight environments. Safety requirements will be strictly adhered to at all times, especially when nitrogen tetroxide and monomethylhydrazine are being handled, because the propellants are not only hypergolic by nature, but highly toxic as well. Individual system components for Phase I and II testing will be tested for proof pressure, leakage, and compatibility with the applicable fluid medium before installation in the breadboard system.

2.3.1.2.3 Phase I Procedure. The command module reaction control system (see Figure 2-3) will be free from contaminates at all times. All components, tubing, and fittings will be purged and decontaminated prior to assembly as a system. The cleaning process to be used on all components, tubing, and fittings will consist of (1) purge with high-flow, dry, filtered nitrogen, (2) flush with trichloroethylene, and (3) purge again with high-flow, dry, filtered nitrogen. All components, tubing, and fittings will be capped immediately after cleaning and will remain capped until installation into the system. All system access ports and instrumentation ports will either be capped or connected at all times to prevent contamination of the system.

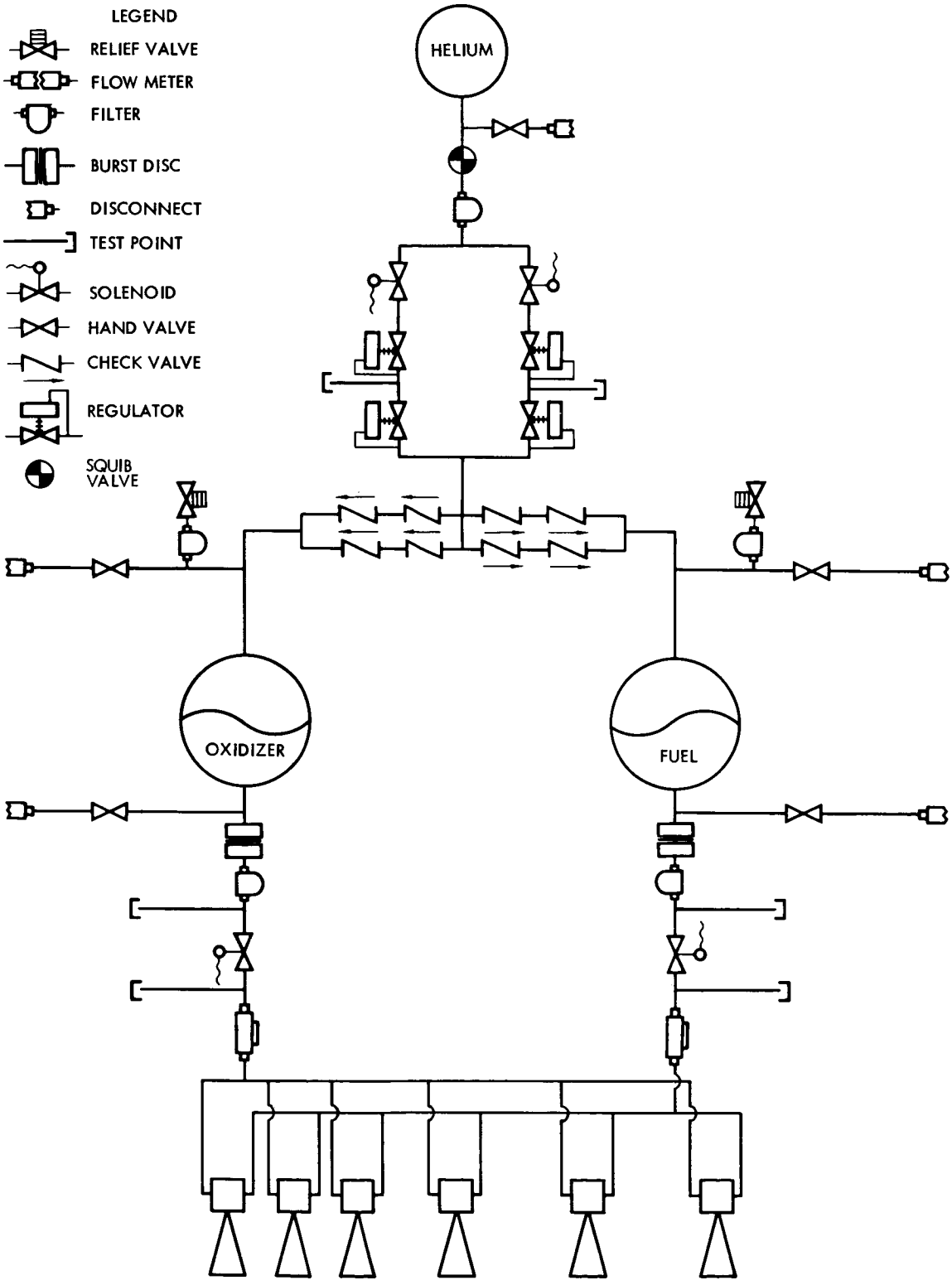


Figure 2-3. Schematic of the Phase 1 Breadboard Command Module Reaction Control System

[redacted]

The following is a list of the pretest conditions to be verified prior to the start of all tests.

1. The system must conform to the test schematic.
2. All plumbing connections must be tight.
3. Electrical wiring must be properly installed.
4. All components must be adequately supported.
5. Instrumentation must be correctly installed.
6. The system shall not leak.

The system test media will be as follows:

1. Nitrogen gas—oil free per specification MIL-N-6011, Grade A, Type I
2. Distilled water having a minimum specific resistivity of 50,000 ohms

The fluid loading lines will consist of clean plumbing and will contain a filter immediately upstream of the test system. The filter will be capable of removing all particles that are larger than 60 microns in size.

At the end of the working day, the system will be depressurized and cleaned. The nitrogen supply system upstream and downstream of the check valves will be carefully depressurized. The propellant tanks and lines will be emptied of water. The system will then be purged and dried with high-flow, dry, filtered nitrogen.

Phase I testing will be divided into two series of tests. Low-response instrumentation will be used during the first series of tests; high-response instrumentation and permanent recording equipment will be used during the second series of tests. Because of the use of low-response instrumentation, the first series of tests will be performed primarily to gain preliminary knowledge of the breadboard system and testing techniques.

Because water will be used in place of the propellants and nitrogen will be used in place of helium during Phase I testing, system temperatures will be monitored during test No. 5 only. The system pressures to be measured during the individual tests are designated in the following detailed descriptions of the tests.

[redacted]

2.3.1.2.3.1 Test No. 1

Objective. The objective of this test is to determine whether a high differential pressure will cause extrusion of the oxidizer and fuel bladders into the small holes of the tank outlets.

Test Program. After installation of the bladder specimen in a test fixture, pressure differentials from 50 to 500 psi will be applied across the specimen for varying time periods. The specimen will be examined after each pressure test.

2.3.1.2.3.2 Test No. 2

Objective. The objective of this test is to verify that the propellant system and the rocket engines function properly.

Instrumentation. Pressure-indicating instruments will be located at points 3, 4, 5, 6, 7, 8, 10, 14, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements).

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 750 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static conditions.

5. All propellant system solenoid valves will be open.

Test Program. A single engine system functional test will be performed by individually actuating the fuel and oxidizer injector valves for five seconds, followed by simultaneous actuation of both fuel and oxidizer injector valves for another five seconds. The test will be performed on each of the six engines.

[redacted]

[redacted]

2.3.1.2.3.3 Test No. 3

Objective. The objective of this test is to determine the maximum amount of water that can be loaded into each of the propellant tanks and to determine the expulsion efficiency of the bladders.

Instrumentation. Pressure gages will be used to indicate system pressure. The water supply tank will be calibrated to indicate the quantity of water contained within the tank.

Test Program. The volumes of the oxidizer tank and the fuel tank will be determined by filling the tanks individually with a known quantity of water from a calibrated supply tank. The expulsion efficiency of the bladders will be established by forcing the water from the system tanks into the calibrated supply tank and observing the quantity of water expelled.

2.3.1.2.3.4 Test No. 4

Objective. The objective of this test is to determine the flow rate of water through the rocket engine injector valves.

Instrumentation. Pressure-indicating instruments will be located at points 7, 8, 10, 14, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static conditions.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

[redacted]AL

Test Program. Flow rates through the engine injector valves will be determined by individual actuation of the fuel and oxidizer valves for 15-second periods, followed by simultaneous actuation of both valves for another 15 seconds. The test will be performed on each of the six engines.

2.3.1.2.3.5 Test No. 5

Objective. The objective of this test is to determine the temperature of the helium entering the propellant tanks during the dump sequence of a pad abort maneuver.

Instrumentation. Pressure-indicating instruments will be located at points 1, 7, 8, 10, and 12, as designated in paragraph 2.3.1.2.1 (Data Requirements). Temperature indicating instruments will be located on the exterior of the helium tank, the outlet of the helium tank, the outlet of each regulator, and the inlet and outlet of the fuel tank.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The fuel manifold line will be disconnected at the outlet port of the fuel solenoid valve and replaced by a 5/8-in. OD flex hose to which is attached a flow control valve and a flow meter. The flow control valve will be adjusted to maintain a flow rate of 6.8 gpm.

3. The oxidizer line will be disconnected at the outlet of the oxidizer tank and replaced by a flex hose to which is attached a solenoid operated valve capable of handling the required flow rate of 30 gpm. A short dump line will be attached to the solenoid operated valve.

4. The fuel solenoid valve will be closed.

5. The oxidizer dump solenoid valve will be closed.

6. The propellant tanks will be filled with water.

7. The helium solenoid valves will be closed.

8. The helium tank and the helium system down to the solenoid valves will be pressurized to 4500 psig with helium.

Test Program. The change in temperature of the helium entering the oxidizer and fuel tanks during a simulated pad abort maneuver will be determined by energizing an oxidizer dump solenoid valve and the fuel system solenoid valve in accordance with a predetermined sequence. The flow in the fuel system will simulate the actuation of the fuel injector valves of five engines simultaneously.

The total time required to dump the water overboard from the propellant tanks will be monitored and recorded.

2.3.1.2.3.6 Test No. 6

Objective. The objective of this test is to determine the operating characteristics of the propellant system during normal system operation.

Instrumentation. Pressure-indicating instruments will be located at points 7, 8, 10, 14, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static conditions.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. Pulse mode performance characteristics of the system during single engine operation will be determined at a regulator inlet pressure of 4500 psig. Instrumentation will be provided to automatically actuate the fuel and oxidizer injector valves of an engine both individually and simultaneously in a firing sequence for periods of time ranging from 10 milliseconds to five seconds duration. The test will be performed on each of the six engines.

2.3.1.2.3.7 Test No. 7

Objective. The objective of this test is to determine the steady-state operating characteristics of the propellant system during simultaneous firing of three engines.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static pressure.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. System performance will be determined during the steady-state firing of three engines. This will be accomplished by actuating simultaneously the fuel and oxidizer injector valves of all combinations of three engines for a time period of ten seconds each.

[redacted]

2.3.1.2.3.8 Test No. 8

Objective. The objective of this test is to determine the water hammer effect on the propellant lines and the pressure surge effect on the helium lines.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47 as designated in paragraph 2.3.1.2.1 (Data Requirements).

System Requirements.

1. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

2. An unfired squib valve will be installed into the system, and the pressure by-pass line parallel to the squib valve will be removed.

3. A burst disc will be installed into both the fuel and oxidizer lines.

4. A pressure no greater than 1 torr will be produced in the following lines:

   (a) Outlet of the burst disc housing to the inlet of each engine

   (b) Outlet of the squib valve to the inlet of the check valves

5. The propellant tanks will be filled with water.

6. The helium tank will be pressurized to 4500 psig with nitrogen.

Test Program. Water hammer effect on the propellant lines and pressure surge effect on the helium lines will be determined by energizing the helium squib valve and recording all pressures at the points designated. The oxidizer and fuel lines will be evacuated prior to the firing of the squib to more closely simulate high-altitude conditions.

2.3.1.2.3.9 Test No. 9

Objective. The objective of this test is to determine the system operating characteristics during simulated regulator failures.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.

2. The helium tank will be pressurized to 4500 psig with nitrogen.

3. The secondary regulator outlet pressure should read 300 psig at static conditions.

4. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

5. The system will include appropriate lines and valves to permit various simulated failures.

Test Program. Regulator failure mode operating characteristics will be determined for single-, dual-, and three-engine operation by simulating individual failures of either the primary or secondary stages of the regulators. By operating valves that have been installed in the system to permit selective routing of the pressurizing gas, the primary or secondary stages of the regulators can be by-passed or blocked. Simultaneous actuation of the fuel and oxidizer injector valves for 10-second periods will be performed while simulating failed-open primary stages, failed-open secondary stages, and failed-closed regulators.

[redacted]

2.3.1.2.3.10 Test No. 10

Objective. The objective of this test is to determine the system operating characteristics during simulated check valve failure.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.
2. The helium tank will be pressurized to 4500 psig with nitrogen.
3. The secondary regulator outlet pressure should read 300 psig at static conditions.
4. With the exception of the engine solenoid valves, all propellant solenoid valves will be open.
5. The system will include appropriate lines and valves to permit various simulated failures.

Test Program. Check valve failure mode operating characteristics will be determined for single-, dual-, and three-engine operation by simulating individual failure of each bank of check valves. By operating valves that have been installed in the system to permit selective routing of the pressurizing gas, each bank of check valves can be by-passed or blocked.

2.3.1.2.3.11 Test No. 11

Objective. The objective of this test is to determine the operating characteristics of the propellant system during a normal entry propellant dump operation.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2. 3. 1. 2. 1 (Data Requirements).

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static pressure.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. Normal entry dump operation will be determined by testing the ability of the system and the time required to dump the remaining propellant. The test will be conducted with 50 percent of the propellant remaining in the tanks.

2.3.1.2.3.12 Test No. 12

Objective. The objective of this test is to determine the operating characteristics of the propellant system during a pad abort dump operation.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements).

System Requirements.

1. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

[redacted]

2. An unfired squib valve will be installed in the system and the pressure by-pass line parallel to the squib valve will be removed.

3. A burst disc will be installed in the fuel and oxidizer lines.

4. The propellant tanks will be pressurized to 4500 psig with nitrogen.

Test Program. The ability of the system to function properly during a simulated pad abort maneuver will be determined by energizing the helium squib valve, the oxidizer overboard dump squib valve, and the propellant tank by-pass squib valves in accordance with a programmed sequence that will include firing five engines simultaneously.

2.3.1.2.3.13 Test No. 13

Objective. The objective of this test is to determine the steady-state operating characteristics of the propellant system during the simultaneous firing of two engines.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static pressure.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. System performance will be determined during the steady-state firing of two engines. This will be accomplished by actuating simultaneously the fuel and oxidizer injector valves of all combinations of two engines for a time period of ten seconds each.

2.3.1.2.3.14 Test No. 14

Objective. The objective of this test is to determine the operating characteristics of the propellant system during single firing of each engine at the various pulse rates.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements).

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static pressure.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. Pulse mode performance characteristics of the system during single engine operating will be determined at a regulator inlet pressure of 4500 psig. Instrumentation will be provided to automatically actuate the fuel and oxidizer injector valves of an engine in a firing sequence for periods of time ranging from 10 milliseconds to 5 seconds duration. The test will be performed on each of the six engines.

2.3.1.2.3.15 Test No. 15

Objective. The objective of this test is to determine the steady-state operating characteristics of the propellant system during single firing of each engine.

Instrumentation. Pressure-indicating instruments will be located at points 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, and 47, as designated in paragraph 2.3.1.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. A pressure by-pass line will be installed parallel to the squib valve.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The regulator outlet pressure should read 300 psig at static pressure.

5. With the exception of the engine solenoid valves, all propellant system solenoid valves will be open.

Test Program. Steady-state single-engine system performance will be determined at a regulator inlet pressure of 4500 psig by actuating the fuel and oxidizer injector valves simultaneously for periods of 30 seconds. The test will be performed on each of the six engines.

2.3.1.2.4 Phase II Procedure. The first series of tests will be performed with distilled water and nitrogen as the fluid media. The purpose of the water tests is four-fold: (1) to provide information to be used in the propellant testing phase, (2) to shakedown the system and instrumentation, (3) to familiarize personnel with the propellant system, and (4) to establish propellant handling techniques. The tests will include propellant tank calibrations, bladder expulsion efficiency tests, and a system functional test. Prior to the functional test, the setup will be checked to verify conformance with the system schematic, tightness of tubing connections, continuity of

electrical systems, and adequacy of support for all components and lines. The propellant tanks will then be filled with distilled water and the helium tank pressurized initially to 500 psig. After the leakproof integrity of the system has been verified, the helium tank will be pressurized to 4500 psig, and the functional test will be performed.

The second series of tests will be performed with the storable propellants and will be divided into two categories: (1) propellant familiarization tests and (2) engine firing tests. Included in the familiarization tests will be propellant tank filling and draining techniques, system purging techniques, and individual fuel and oxidizer flow tests through the rocket engines. When performing the engine hot-firing tests, the test setup will be examined for adequacy of heat shielding for all instrumentation in addition to the established pretest system checks. The propellant tanks will then be filled with the storable propellants in accordance with detailed procedures developed and verified during the familiarization testing period. The helium tank will be pressurized initially to 500 psig, and after the leakproof integrity of the system has been verified, it will be pressurized to 4500 psig. Initial pressure and temperature readings will be recorded and the recording instruments started. This procedure will be followed for all the engine firing tests that will include single and multiple engine steady-state operation, single and multiple engine pulsing operation, simulated mission sequences, and component malfunction tests. After each testing period, the recorded data and test setup will be examined for inconsistencies, the tanks and lines will be emptied of propellants, and the systems will be cleaned and purged.

Upon satisfactory completion of the first two series of tests, the Phase II program may be augmented by a series of trouble-shooting tests, integrated systems tests, and other special tests, as required. The integrated systems include the RCS and those portions of the guidance and control system that supply the programmed signals for the controlled firing of the rockets, both automatically and manually. Simulated signals from the guidance and control system will be used where feasible.

2.3.1.2.5 Phase III Procedure. The test procedures for Phase III will be the same as those for Phase II, except for the incorporation of improved testing techniques developed during Phase II.

2.3.1.3 Equipment

The equipment required to accomplish the objectives of the breadboard test program will include a test stand; pressure, temperature, and flow sensing elements; indicating and recording equipment; and miscellaneous support equipment.

The test stand will be a full-scale sheet metal mock-up of the RCS compartments. The internal configuration of the compartments will be identical to the command module with the exception of the materials of construction. The outer configuration of the command module in the area of the rocket engines will be duplicated as accurately as possible to provide realistic nozzle exit conditions. The test stand will be updated throughout the test program.

A general list of the types of sensing elements, recording equipment, and miscellaneous equipment required for the test program follows:

1. Oscillograph (direct write, 18-channel, electronic flash timing)
2. Amplifiers (wide-band, dc with attenuators)
3. Temperature recorder (1/2 sec full-scale response; chart speed 6, 12, 24, and 30 in. per sec)
4. Oscillators, battery powered
5. Pulse rate convertor
6. Calibrated and sensitivity thermocouple, 12-channel unit
7. Thermocouple reference junction (rack mount, rear input and output)
8. Signal conditions module racks
9. Cabinets (plates, shelves, strips, panels, doors, frames, side panels)
10. X-Y plotter, dual pen
11. Pressure regulators (0 to 5000 psig)
12. Accumulators
13. Pressure regulators (0 to 3600 psig)
14. Galvanometers
15. Pressure transducers (0 to 500 psig)
16. Pressure transducers (0 to 5000 psig)

17. Signal conditioning module, power supply

18. Flow strain gage (liquid, 0 to 10 gpm, 1 percent linearity, output voltage 4 millivolts per volt

19. Thermocouple pick-ups

20. Check valves

21. Ball valves

22. Filters

23. Pressure gages

24. Solenoid valves

25. Switch, crossbar

26. Connectors (hold, terminal plug)

27. Cards (transducer bridge, circuit structure)

28. Cards (galvanometer drive, circuit structure)

29. Wire (6 conductor, shielded, 22 gage, texlon inpregnated)

30. Connector, (wall receptacle, 7 pin)

31. Personnel protective clothing with accessories, such as airpacks, breathing canisters, face shields, gloves, boots, aprons, etc.

32. Special personnel protective equipment, such as air sampling analyzer, hydrazine analyzer, N_2O_4 analyzer, and a MMH analyzer.

33. Decontamination equipment including vapor degreaser, black light analyzer, storage bag sealing kit, etc.

2.3.1.4 Facilities

A special test facility for the breadboard test program will be constructed at the S&ID facility in Downey, California. No attempt will be made to simulate altitude in these tests. The facility design and its operation will comply with all sections and paragraphs of Air Force technical manual T. O. 11C-1-6(1). The import design and operation details include explosion

[redacted]

hazard control, toxicity hazard control, ventilation scrubber system, fuel and oxidizer scrubber systems, test personnel protection, toxic detectors, visual and audible warning system, meteorological instruments, control room ventilation system, and safety showers and eyewash basins.

2.3.1.5 Test Schedule

The test schedule for breadboard testing of the command module RCS is shown in Figure 2-4.

2.3.2 Breadboard Testing of the Apollo Service Module RCS

2.3.2.1 Objectives

The breadboard testing of the service module RCS (see Figure 2-5) will accomplish the following objectives.

1. Provide experimental evaluation of the integrated system
2. Prove design concepts
3. Resolve design difficulties
4. Ensure compatibility of components
5. Provide data for system calibration
6. Resolve propellant handling techniques
7. Verify the suitability of the system for ultimate use

2.3.2.2 Test Plan

The testing of the breadboard system will be divided into three progressive phases: Phase I, Phase II, and Phase III. The major differences among the test phases will be the types of components used in the test setups and the fluid media used during the test runs. Phase I testing will employ available off-the-shelf components that will fulfill the preliminary design requirements. The fluid media to be used during Phase I will be water and nitrogen.

Phase II components will be flight articles which satisfy the requirements of North American equipment specifications but which have not completed qualification testing. Phase III components will be fully qualified articles. The fluid media to be used during Phase II and Phase III testing will initially be distilled water and will ultimately be the hypergolic propellants.

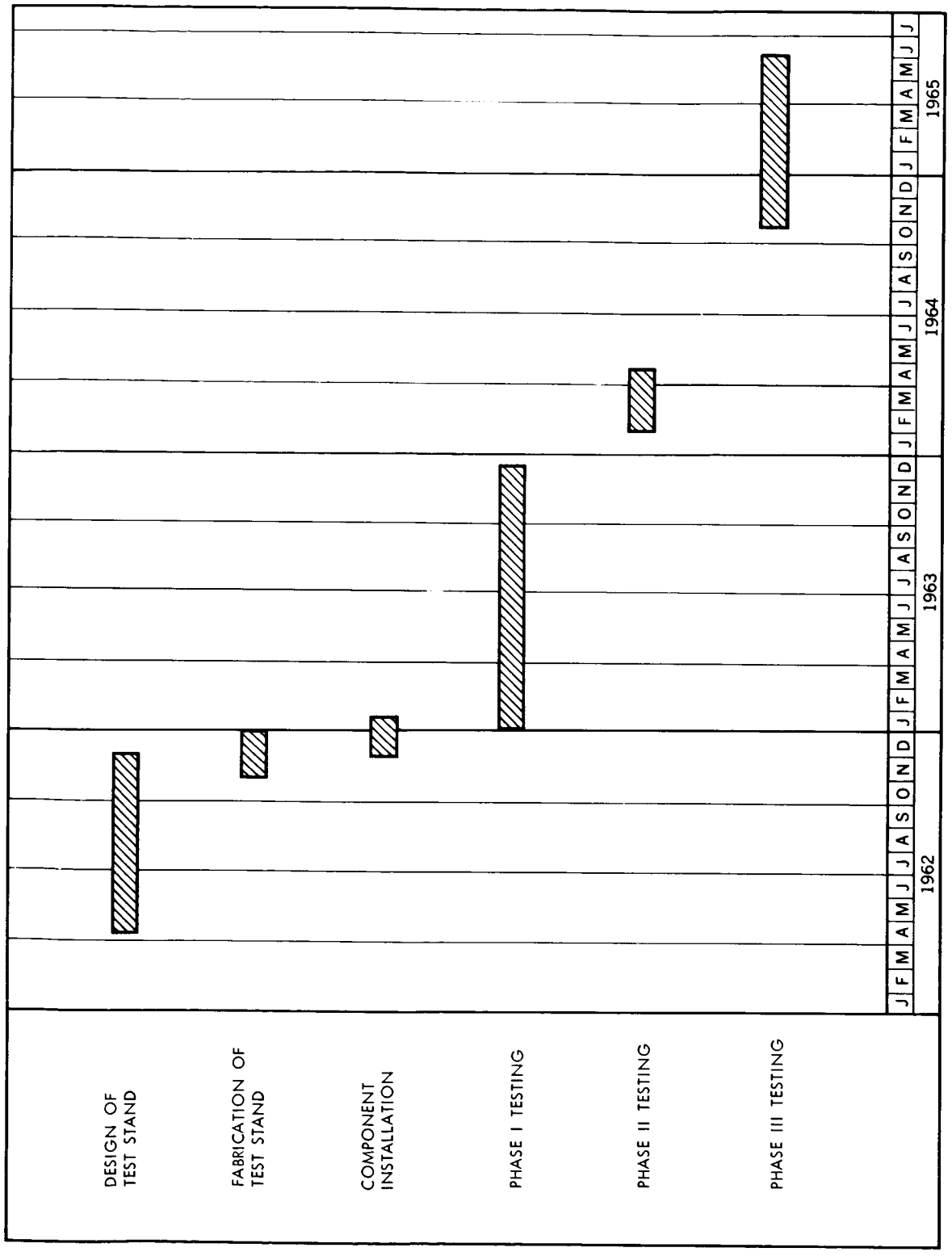


Figure 2-4. S&ID Schedule of Command Module Reaction Control System Breadboard Tests

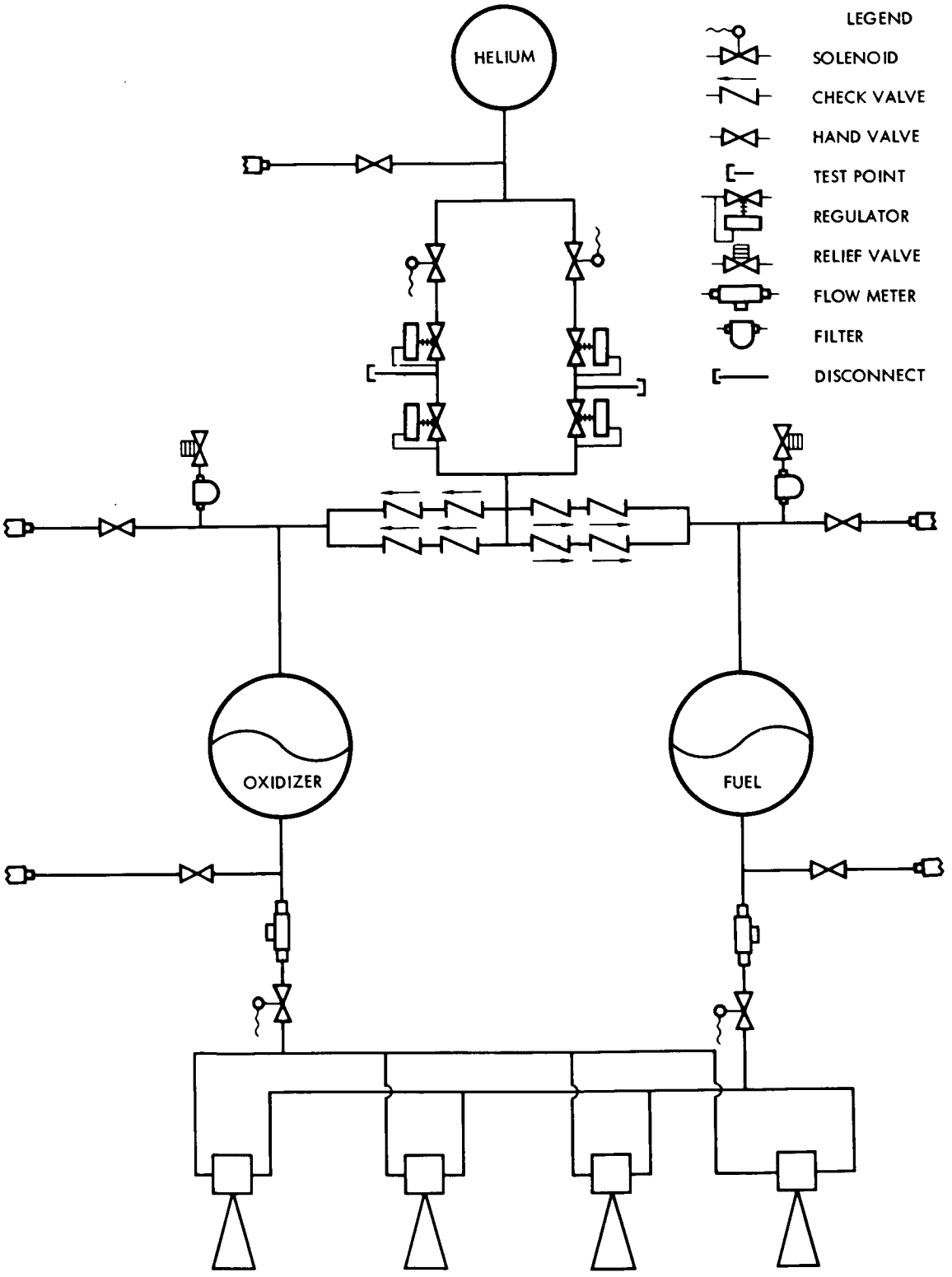


Figure 2-5. Service Module Reaction Control Propellant Feed Subsystem Flow Diagram

2.3.2.2.1 Data Requirements. During the testing of the service module RCS, the following list will be monitored and recorded:

1. Pressure of gas in helium tank
2. Temperature of gas in helium tank
3. Outlet pressure of primary stage of regulator No. 1
4. Outlet pressure of primary stage of regulator No. 2
5. Outlet pressure of secondary stage of regulator No. 1
6. Outlet pressure of secondary stage of regulator No. 2
7. Inlet pressure of check valve assembly
8. Pressure of gas in fuel tank on gas side of bladder
9. Temperature of gas in fuel tank on gas side of bladder
10. Pressure of fuel in fuel tank on fuel side of bladder
11. Temperature of fuel in fuel tank on fuel side of bladder
12. Pressure of gas in oxidizer tank on gas side of bladder
13. Temperature of gas in oxidizer tank on gas side of bladder
14. Pressure of oxidizer in oxidizer tank on oxidizer side of bladder
15. Temperature of oxidizer in oxidizer tank on oxidizer side of bladder
16. Outlet pressure of fuel solenoid valve
17. Outlet pressure of oxidizer solenoid valve
18. Flow rate of fuel
19. Flow rate of oxidizer
20. Pressure in fuel line of -Y engine
21. Temperature in fuel line of -Y engine

[redacted]

22. Pressure in oxidizer line of -Y engine

23. Temperature in oxidizer line of -Y engine

24. Pressure in fuel line of -R engine

25. Temperature in fuel line of -R engine

26. Pressure in oxidizer line of -R engine

27. Temperature in oxidizer line of -R engine

28. Pressure in fuel line of +Y engine

29. Temperature in fuel line of +Y engine

30. Pressure in oxidizer line of +Y engine

31. Temperature in oxidizer line of +Y engine

32. Pressure in fuel line of +R engine

33. Temperature in fuel line of +R engine

34. Pressure in oxidizer line of +R engine

35. Temperature in oxidizer line of +R engine

36. Pressure in engine chamber of -Y engine

37. Pressure in engine chamber of -R engine

38. Pressure in engine chamber of +Y engine

39. Pressure in engine chamber of +R engine

2.3.2.2.2 Test Procedures. The service module reaction control system consists of four similar, independent systems. For breadboard test purposes, only two systems will be used, and these will be identified as system A and system B. Off-the-shelf components will be installed on system A for Phase I testing. Components that meet S&ID specifications, but have not been qualified, will be installed on system B for Phase II testing. During Phase II testing, system A will be reworked to incorporate qualified components for Phase III testing. At the conclusion of Phase II testing, system B will be reworked to incorporate qualified components for Phase III testing. The two systems will be tested during Phase III.

The tests will be performed at existing ambient conditions of pressure and temperature with no attempt to simulate flight environments. Safety requirements will be strictly adhered to at all times, especially when nitrogen tetroxide and hydrazine/unsymmetrical-dimethylhydrazine are being handled, because the propellants are not only hypergolic by nature, but highly toxic as well. Individual system components will be tested for proof pressure, leakage, and compatibility with the applicable fluid medium before installation in the breadboard system.

2.3.2.2.3 Phase I - Procedure. The service module reaction control system will be free from contaminates at all times. All components, tubing, and fittings will be purged and decontaminated prior to assembly as a system. The cleaning process to be used on all the components, tubing, and fittings will consist of (1) purge with high flow, dry, filtered nitrogen, (2) flush with trichloroethylene, and (3) purge again with high-flow, dry, filtered nitrogen. All components, tubing, and fittings will be capped immediately after cleaning and will remain capped until installation into the system. All system access ports and instrumentation ports will either be capped or connected at all times to prevent contamination of the system.

The following is a list of the pretest conditions to be verified prior to the start of all tests.

1. Conformance of the system to the test schematic
2. Tightness of all mechanical fluid connections
3. Proper installation of electrical wiring
4. Adequate support of all components
5. Correct installation of instrumentation
6. Leakproof integrity of system

The system test media will be as follows:

1. Nitrogen gas—oil free per Specification MIL-N-6011 Grade A, Type I
2. Distilled water having a minimum specific resistivity of 50,000 ohms

[redacted]

The fluid filling lines will consist of clean plumbing and will contain a filter immediately upstream of the test system. The filter will be capable of removing all particles that are larger than 60 microns in size.

At the end of the working day, the system will be depressurized and cleaned. The nitrogen supply system upstream and downstream of the check valves will be depressurized carefully. The propellant tanks and lines will be emptied of water. The system will then be purged and dried with high-flow, dry, filtered nitrogen.

Phase I testing will be divided into two series of tests. Low response instrumentation will be used during the first series of tests; high response instrumentation and permanent recording equipment will be used during the second series of tests. Because of the use of low-response instrumentation, the first series of tests will be performed primarily to gain preliminary knowledge of the breadboard system and testing techniques.

Because water will be used in place of the propellants and nitrogen will be used in place of helium during Phase I testing, system temperatures will not be monitored. The system pressures to be measured during the individual tests are designated in the following detailed descriptions of the tests.

2.3.2.2.3.1 Test No. 1

Objective. The objective of this test is to determine whether a high differential pressure will cause extrusion of the oxidizer and fuel bladders into the small holes of the tank outlets.

Test Program. After installation of the bladder specimen in a test fixture, pressure differentials of 50 to 550 psi will be applied across the specimen for varying time periods. The specimen will be examined after each pressure test.

2.3.2.2.3.2 Test No. 2

Objective. The objectives of this test are to determine the maximum amount of water that can be loaded into each of the propellant tanks and to determine the expulsion efficiency of the bladders.

Instrumentation. Pressure gages will be used to indicate system pressures. The water supply tank will be calibrated to indicate the quantity of water contained within the tank.

Test Program. The volumes of the oxidizer tank and the fuel tank will be determined by filling the tanks individually with a known quantity of water from the calibrated supply tank. The expulsion efficiency of the bladders can be established by forcing the water from the system tanks into the calibrated supply tank and observing the quantity of water expelled.

2.3.2.2.3.3 Test No. 3

Objective. The objective of this test is to verify that the propellant system and the rocket engines function properly.

Instrumentation. Pressure-indicating instruments will be located at points 1, 5, 6, 8, 12, 20, 22, 24, 26, 28, 30, 32, and 34, as designated in paragraph 2.3.2.2.1 (Data Requirements).

System Requirements.

1. The propellant tanks will be filled with water.
2. The helium tank will be pressurized to 750 psig with nitrogen.
3. The regulator outlet pressure should read 190 psig at static conditions.
4. All propellant system solenoid valves will be open.

Test Program. A single-engine system functional test will be performed by individually actuating the fuel and oxidizer injector valves for five seconds, followed by simultaneous actuation of both fuel and oxidizer injector valves for another five seconds. The test will be performed on each of the four engines.

2.3.2.2.3.4 Test No. 4

Objective. The objective of this test is to determine the size of a flow restrictor that must be installed on the engines to produce the required 90 psia engine chamber pressure.

[redacted]

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. An orifice plate adapter and an orifice plate will be installed on each of the four engines.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 2100 psig with nitrogen.

4. The regulator outlet pressure should read 190 psig at static conditions.

5. All propellant system solenoid valves will be open.

Test Program. The 90 psia chamber pressure generated during engine firing will be duplicated by means of the flow restricting orifice attached to each engine; the chamber pressure will be determined by the flow of water through the system at normal propellant flow rates. The fuel and oxidizer injector valves of individual engines will be actuated simultaneously until the engine chamber pressure is constant.

2.3.2.2.3.5 Test No. 5

Objective. The objective of this test is to determine the flow rate of water through the rocket engine injector valves.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.

2. The helium tank will be pressurized to 2100 psig with nitrogen.

3. The regulator outlet pressure should read 190 psig at static conditions.

4. All propellant system solenoid valves will be open.

Test Program. Flow rates through the engine injector valves will be determined by individual actuation of the fuel and oxidizer valves for 15-second periods, followed by simultaneous actuation of both valves for another 15 seconds. The test will be performed on each of the four engines.

2.3.2.2.3.6 Test No. 6

Objective. The objective of this test is to determine the operating characteristics of the propellant system during normal system operation.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.

2. The helium tank will be pressurized with nitrogen as follows:

   Test No. 6A, 2100 psig

   Test No. 6B, 4500 psig

3. The regulator outlet pressure should read 190 psig at static conditions.

4. All propellant system solenoid valves will be open.

Test Program. Single engine system performance and flow rates through the engine injector valves will be determined during steady-state flow for periods up to one minute. After actuating the fuel and oxidizer injector valves individually for 10 seconds each, the valves will be actuated simultaneously for periods of 30 seconds and then 60 seconds. The test will be performed on each of the four engines.

2.3.2.2.3.7 Test No. 7

Objective. The objective of this test is to determine the system operating characteristics during simulated regulator failures.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 3, 4, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The system will include appropriate lines and valves to permit the following simulated failures.

   a. Primary stage of regulator No. 1 failed open.

   b. Primary stage of regulator No. 2 failed open.

   c. Secondary stage of regulator No. 1 failed open.

   d. Secondary stage of regulator No. 2 failed open.

   e. Regulator No. 1 failed closed.

   f. Regulator No. 2 failed closed.

2. The propellant tanks will be filled with water.

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The secondary regulator outlet pressure should read 190 psig at static conditions.

5. All propellant system solenoid valves will be open.

Test Program. Regulator failure mode operating characteristics will be determined for single- and dual-engine operation by simulating individual failures of either the primary or secondary stages of the regulators. By operating valves that have been installed in the system to permit selective routing of the pressurizing gas, the primary or secondary stages of the regulators can be by-passed or blocked. Simultaneous fuel and oxidizer injector valve actuation for 10-second periods will be performed while simulating failed-open primary stages, failed-open secondary stages, and failed-closed regulators.

2.3.2.2.3.8 Test No. 8

Objective. The objective of this test is to determine the system operating characteristics during simulated check valve failures.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow measuring instruments and at points, 1, 5, 6, 7, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The system will include appropriate lines, valves, or other hardware to simulate one failed-closed check valve in each of the four branches of the check valve assembly.

2. The propellant tanks will be filled with water.

[redacted]

3. The helium tank will be pressurized to 4500 psig with nitrogen.

4. The secondary regulator outlet pressure should read 190 psig at static conditions.

5. All propellant system solenoid valves will be open.

Test Program. Check valve failure mode operating characteristics will be determined for single- and dual-engine operation by simulating a failed-closed check valve in the check valve assembly. By blocking one of the four branches of the assembly, a failed-closed condition can be duplicated. Simultaneous fuel and oxidizer injector valve actuation for 10 second periods will be performed for a check valve failure in each of the four branches of the assembly.

2.3.2.2.3.9 Test No. 9

Objective. The objective of this test is to determine the steady-state operating characteristics of the propellant system during dual-engine operation.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.

2. The helium tank will be pressurized to 4500 psig with nitrogen.

3. The secondary regulator outlet pressure should read 190 psig at static conditions.

4. All propellant system solenoid valves will be open.

[redacted]

Test Program. Steady-state dual-engine system performance will be determined by simultaneous actuation of the injector valves of two adjacent engines. The period of actuation will be for 30 seconds and will be performed on each of the four combinations of adjacent engines.

2.3.2.2.3.10 Test No. 10

Objective. The objective of this test is to determine the steady-state operating characteristics of the propellant system during single-engine operation.

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.
2. The helium tank will be pressurized to 4500 psig with nitrogen.
3. The secondary regulator outlet pressure should read 190 psig at static conditions.
4. All propellant system solenoid valves will be open.

Test Program. Steady-state single-engine system performance will be determined by actuating the fuel and oxidizer injector valves simultaneously for periods of 30 seconds. The test will be performed on each of the four engines.

2.3.2.2.3.11 Test No. 11

Objective. The objective of this test is to determine the pulse mode operating characteristics of the propellant system during single-engine operation.

[redacted]

[redacted]

Instrumentation. Pressure-indicating instruments will be located at the inlet and/or outlet of the flow-measuring instruments and at points 1, 5, 6, 8, 10, 12, 14, 20, 22, 24, 26, 28, 30, 32, 34, 36, 37, 38, and 39, as designated in paragraph 2.3.2.2.1 (Data Requirements). Instruments for measuring flow will be located in both the oxidizer and fuel feed lines.

System Requirements.

1. The propellant tanks will be filled with water.

2. The helium tank will be pressurized to 4500 psig with nitrogen.

3. The secondary regulator outlet pressure should read 190 psig at static conditions.

4. All propellant system solenoid valves will be open.

Test Program. Pulse mode performance characteristics of the system will be determined during single-engine operation. Instrumentation will be provided to automatically actuate the fuel and oxidizer injector valves of an engine both individually and simultaneously in a firing sequence for periods of time ranging from 10 milliseconds to 5 seconds duration. The test will be performed on each of the four engines.

2.3.2.2.4 Phase II Procedure. The first series of tests will be performed with distilled water and nitrogen as the fluid media. The purpose of the water tests is four-fold: (1) to provide information to be used in the propellant testing phase, (2) to shakedown the system and instrumentation, (3) to familiarize personnel with the propellant system, and (4) to establish propellant handling techniques. The tests will include propellant tank calibrations, bladder expulsion efficiency tests, and a system functional test. Prior to the functional test, the setup will be checked to verify conformance with the system schematic, tightness of tubing connections, continuity of electrical systems, and adequacy of support for all components and lines. The propellant tanks will then be filled with distilled water and the helium tank pressurized initially to 500 psig. After the leakproof integrity of the system has been verified, the helium tank will be pressurized to 4500 psig, and the functional test will be performed.

The second series of tests will be performed with the storable propellants and will be divided into two categories: (1) propellant

[redacted]FIAL

familiarization tests and (2) engine firing tests. Included in the familiarization tests will be propellant tank filling and draining techniques, system purging techniques, and individual fuel or oxidizer flow tests through the rocket engines. When performing the engine hot-firing tests, the test setup will be examined for adequacy of heat shielding for all instrumentation in addition to the established pretest system checks. The propellant tanks will then be filled with the storable propellants in accordance with detailed procedures developed and verified during the familiarization testing period. The helium tank will be pressurized initially to 500 psig, and after the leakproof integrity of the system has been verified, it will be pressurized to 4500 psig. Initial pressure and temperature readings will be recorded and the recording instruments started. This procedure will be followed for all the engine firing tests that will include single- and dual-engine steady-state operation, single- and dual-engine pulsing operation, simulated mission sequences and component malfunction tests. After each testing period, the recorded data and test setup will be examined for inconsistencies, the tanks and lines will be emptied of propellants, and the systems will be cleaned and purged.

Upon satisfactory completion of the first two series of tests, the Phase II program may be augmented by a series of trouble-shooting tests, integrated systems tests, and other special tests, as required. The integrated systems include the RCS and those portions of the guidance and control system that supply the programmed signals for the controlled firing of the rockets, both automatically and manually. Simulated signals from the guidance and control system will be used where feasible.

2.3.2.2.5 Phase III Procedure. The test procedures for Phase III will be similar to those for Phase II except for the incorporation of improved testing techniques developed during Phase II.

2.3.2.3 Equipment

The equipment required to accomplish the objectives of the breadboard test program will include a test stand; pressure, temperature, and flow sensing elements; indicating and recording equipment; and miscellaneous support equipment.

The test stand will be a tubular steel framework to which is attached a full-scale metal mock-up of a service module RCS package. The RCS package will support the helium and propellant tanks, the numerous components that make up the pressurization and propellant distribution subsystems, and the cluster of four rocket engines.

The sensing elements, recording equipment, and miscellaneous equipment required for the test program are essentially the same as those

[redacted]

items listed in the breadboard tests of the reaction control for the command module. (See paragraph 2.3.1.3.)

2.3.2.4 Facilities

Facilities required for the breadboard testing of the service module RCS are essentially the same as those listed in the command module reaction control breadboard tests. (See paragraph 2.3.1.4.)

2.3.2.5 Test Schedule

The test schedule for the service module RCS is shown in Figure 2-6.

2.3.3 Testing of Propellant Flow into Evacuated Lines

2.3.3.1 Objectives

This test will determine the existence and possible solution of potential freezing problems resulting from the introduction of propellant into evacuated lines at temperatures and pressures existing in the command module RCS prior to entry.

The tests encompass two phases:

1. Phase I testing will use water as the test fluid and will determine the significant effects of (1) test fluid temperature, (2) pressure of the evacuated system, and (3) system volume.

2. The analysis of Phase II testing will determine the possibility of propellant freezing. This phase is an abbreviated schedule of tests conducted under conditions more severe than those actually existing. Since the N_2O_4 propellant is most likely to freeze, it will be tested prior to MMH, which freezes at 12 F. No further testing will be done if the N_2O_4 does not freeze and the results of Phase I testing do not indicate any unexpected effects as the different system parameters are varied. If the tests indicate the possibility that freezing will occur, the test program will be expanded to include testing of MMH under extreme conditions. If the results of Phase II testing, using either propellant, indicate possible freezing, the results of Phase I testing will be used to determine possible solutions to the freezing problem. After an analysis of Phase I, further tests will be conducted; the extent of these additional tests will be dictated by the results of Phase I. The data from the additional testing will also be analyzed.

[redacted]

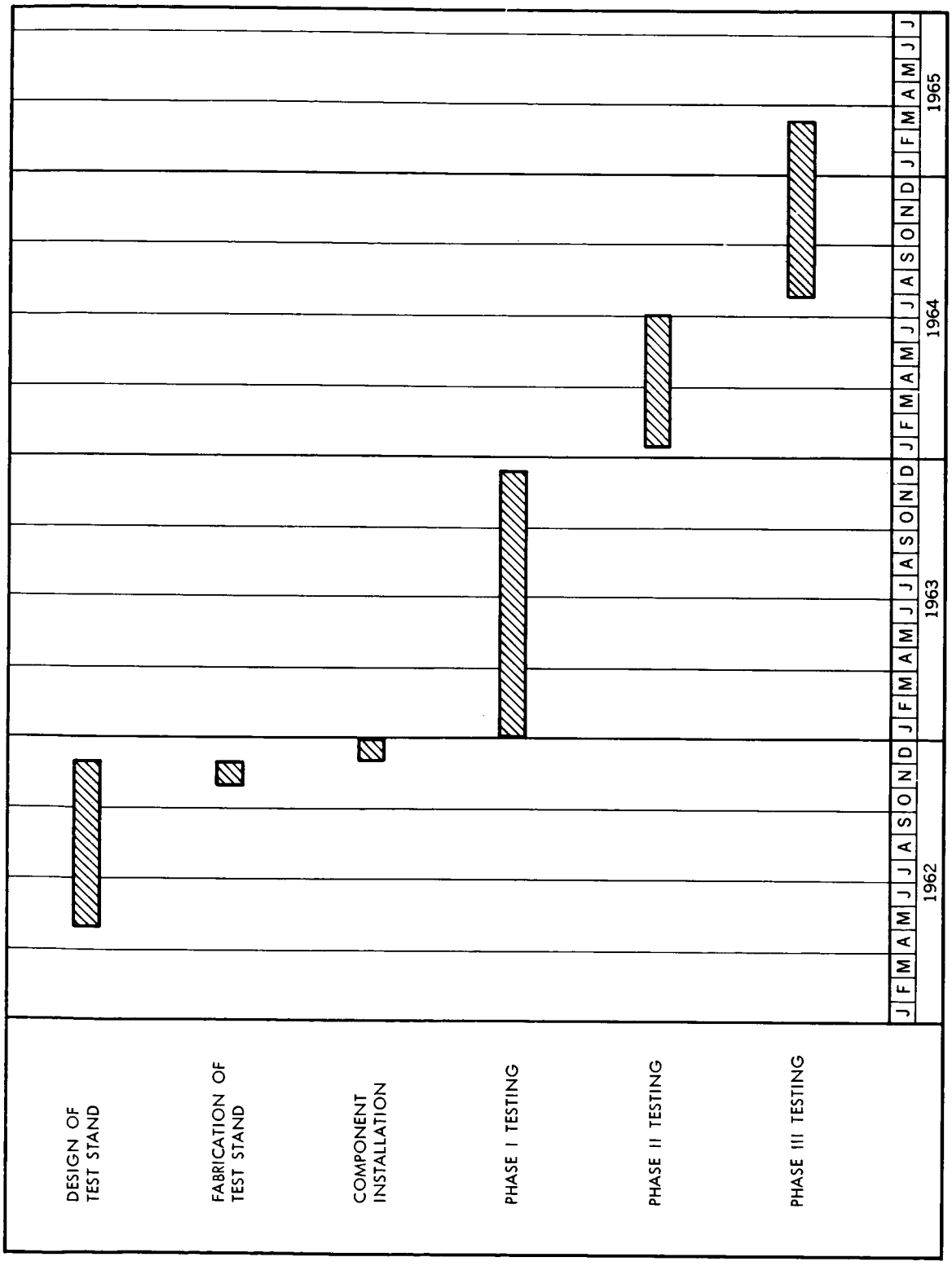


Figure 2-6. S&ID Schedule of Service Module Reaction Control System Breadboard Tests

[redacted]

2.3.3.2 Test Plan

Phase I and Phase II testing are conducted at the following conditions:

Test Number	Evacuated System Pressure (psia)	Test Fluid Temperature (deg F)	Accumulator Volume (liters)	Storage Tank Pressure (psia)
Phase I - Test Fluid is Water				
I-1	0.005	40±2	12	20
I-2	0.010	40±2	12	20
I-3	0.020	40±2	12	20
I-4	0.005	60±2	12	20
I-5	0.005	80±2	12	20
I-6	0.005	40±2	12	20
Phase II - Test Fluid is N_2O_4				
II-1	0.005	40±2	12	20
II-2	0.005	40±2	12	20
Phase II* - Test Fluid is MMH				
II-3	0.005	40±2	12	20
II-4	0.005	40±2	12	20

*These tests to be conducted only if results of tests with N_2O_4 reveal possible freezing.

2.3.3.3 Equipment

A breadboard system, shown in Figure 2-7, is required for the tests. The tests will be conducted as follows:

1. The propellant storage tank will be filled with enough propellant to fill the system downstream.

2. The propellant tank then will be pressurized using gaseous nitrogen. The solenoid valve, SV_1, will be closed during this operation.

3. The propellant line will be evacuated through valve V_1, then this valve will be closed.

[redacted]

4. The propellant will be brought to the desired temperature.

5. When the desired test conditions are achieved, the solenoid valve, SV_1, will be opened to allow the propellant to flow into the line and the accumulator. The resultant temperatures and pressures will be recorded.

2.3.3.4 Facilities

The tests will be accomplished at the S&ID, Downey, laboratory, subject to safety restrictions in effect at the time of the tests.

2.3.3.5 Test Schedule

Figure 2-8 shows the proposed test schedule.

Test Phases I and II have been completed with no indication of propellant freezing observed; consequently, Phase III will not be conducted.

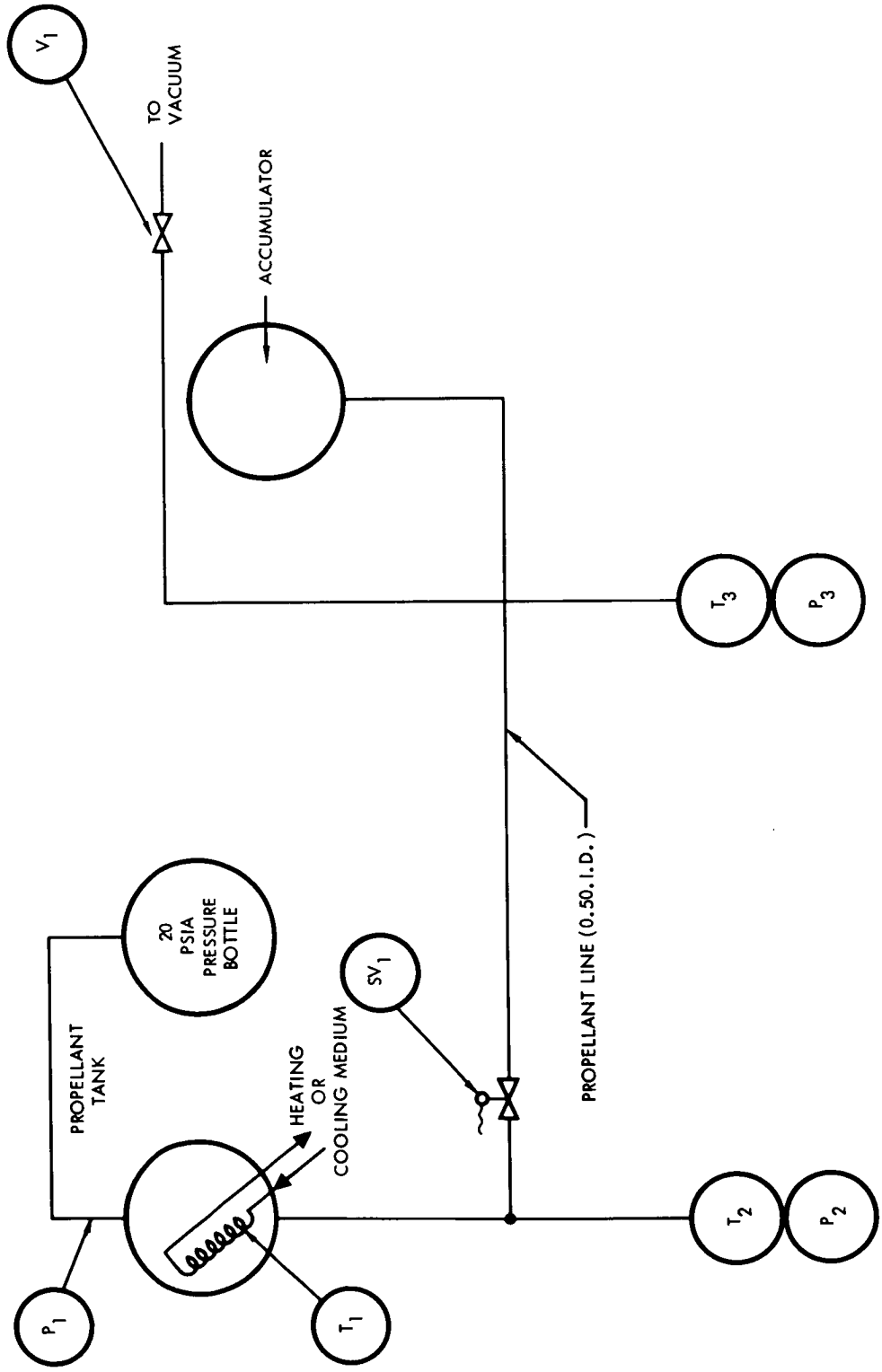


Figure 2-7. Command Module Propellant Flow Test Diagram

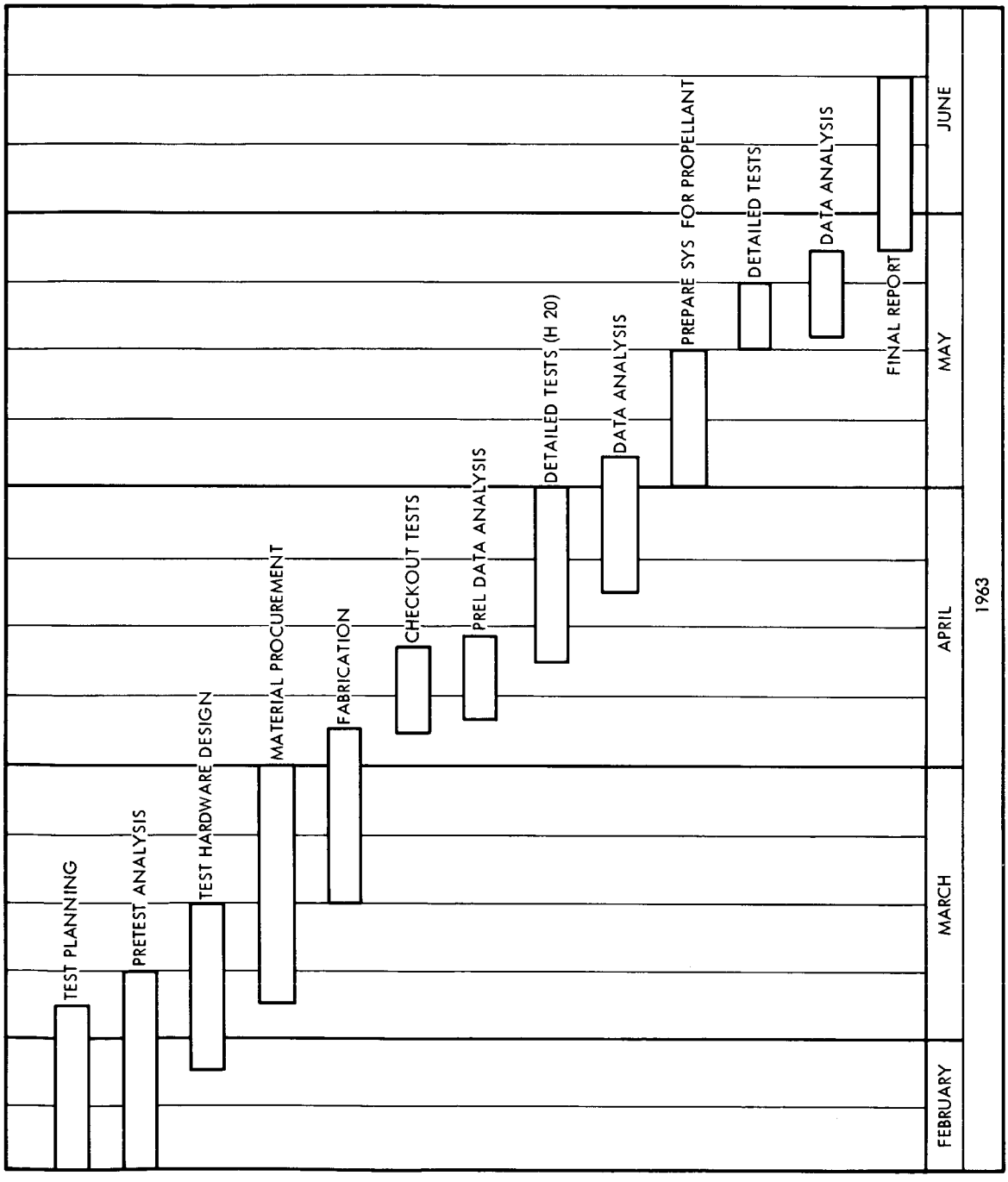


Figure 2-8. S&ID Schedule Command Module Propellant Flow Tests

3.0 LAUNCH ESCAPE SYSTEM

3.1 SCOPE

During the launch escape system development program, the rocket motor igniters will be tested in inert simulated ignition chambers. The launch escape, pitch control, and tower jettison motors will be statically fired to evaluate motor and solid propellant characteristics. Two simulated altitude performance tests will be required as part of the tower jettison motor development program to attain the optimum design prior to flight testing. Flight test evaluation will be accomplished by means of pad abort and Little Joe II abort tests.

3.2 SUBCONTRACTOR TEST PLAN

3.2.1 Launch Escape Rocket Motor Tests (Lockheed Propulsion Company)

3.2.1.1 Objective

Completion of the launch escape motor development test program will assure the optimum configuration of motor components. The development tests will yield data on igniter and motor performance necessary for proper design evaluation of all motor components. Development testing will also produce a unit of finalized design worthy of entering a qualification test program.

3.2.1.2 Test Plan

Prior to full scale static motor tests, the launch escape rocket motor igniter will undergo a short development program. The igniter development program consists of ten igniter firings using exploding bridge wire initiators. The initial two tests are scheduled as open-air firings. Two igniters will be fired into igniter test chambers that simulate the free volume of the motor. The test program will continue with two igniter firings accomplished under simulated altitude ignition conditions. These first six igniter development tests will be accomplished prior to the first full-scale launch escape motor firing. A batch check igniter and an igniter in conjunction with the first live motor will be tested. The program will be concluded with two igniters fired under simulated altitude ignition conditions. These last two tests will phase

[redacted]

over into the early part of the motor development program allowing minor igniter modifications to be accomplished—modifications based on results obtained from launch escape motor firings. Test firings with hot wire igniter cartridges will include pellet baskets, pyrogens, and the last three development motor firings.

The launch escape motor development program consists of 17 units, 15 of which are scheduled to be statically fired. Two motors will undergo destructive tests without static firing as described below.

The first three development test motors will be temperature conditioned to 70 F, 140 F, and 20 F respectively and statically fired at ambient pressure. These firings serve primarily as ballistic checkout and design verification tests over the motor temperature operating range.

Motor No. T-4 will be temperature cycled between -20 F and 140 F for two full cycles and then fired at a temperature of 20 F. The temperature cycling test will demonstrate the ability of the propellant grain assembly to perform within NAA specification MC901-0002.

The fifth development test motor will be fired at 70 F and at simulated altitude ignition conditions without undergoing any other environmental treatment; the motor firing will provide additional data for ballistic and ignition performance evaluation.

A temperature conditioning to destruction type test will be accomplished on the sixth development motor. The unit will be conditioned to successively lower temperatures, starting at 70 F, until propellant grain structural failure occurs. The motor will be instrumented in order to obtain physical properties data of the grain configuration.

Development test motor No. T-7 will be utilized in a joint S&ID and Lockheed Propulsion Company ground test. The primary objective of this static test is verification of the tower structural integrity during launch escape motor operation. However, data taken by Lockheed from the motor firing will serve as ballistic, temperature, strain, and vibration data.

Another ballistic evaluation firing will be accomplished with development motor No. T-8. The motor will be tested at 70 F and at ambient pressure.

Motor No. T-9 will undergo packaged drop testing in order to determine propellant behavior in a simulated transportation shock environment. This motor will contain an inert propellant with physical properties similar to those of the live propellant.

The tenth development motor will undergo 75 days of accelerated aging at 160 F. Subsequently, the unit will be statically tested at 140 F. The aging program is designed to simulate the five-year storage life period specified in the NAA Motor Procurement Specification, MC901-0002.

Motor No. T-11 will be temperature cycled between -20 F and 140 F for two full cycles and then fired at 140 F. The temperature cycling test will demonstrate the ability of the propellant grain assembly to perform within NAA specification MC901-0002.

A temperature gradient test will be imposed on Motor No. T-12 before static firing. The motor will be conditioned to a temperature of 20 F and then exposed to 140 F until the maximum attainable temperature gradient exists across the motor grain. At that time, the motor will be statically fired. The ballistic effects of propellant temperature gradients will be determined from the motor firing data.

The next development test motor, No. T-13, will be subjected to sequential environments of temperature cycling, vibration, and packaged drop-testing. The unit then will be fired statically after being conditioned to 70 F. The sequential environmental treatment imposed upon this motor will be similar to those imposed during the qualification program and will allow motor performance evaluation under these conditions.

The next two motors, No. T-14 and T-15, will be subjected to temperature cycling, packaged drop-testing, and altitude cycling. The motors then will be statically fired at 20 F and 70 F respectively and under simulated altitude conditions.

Motor No. T-16 will be temperature cycled between -20 F and 140 F for two full cycles and then fired at 20 F. The temperature cycling test will demonstrate the ability of the propellant grain assembly to perform within NAA specification MC901-0002.

Phase I, the launch escape motor development program, will be concluded with motor No. T-17. The temperature gradient treatment on motor No. T-12 will be repeated on this unit. However, this unit will be conditioned to the high temperature first and fired after attaining the propellant temperature gradient by exposure to low temperature.

3.2.1.3 Equipment

Test equipment for the launch escape motor development program will consist of a three-component thrust stand, motor-conditioning equipment, motor-handling equipment, and a data acquisition system. Altitude ignition simulation equipment, hydrotest, and vibration equipment will also be required.

[redacted]

3.2.1.4 Facilities

The launch escape motor development program will be performed at the existing facilities of the Lockheed Propulsion Company at Redlands and Potrero, California.

3.2.1.5 Test Schedule

The test schedule for the launch escape motor development program is shown in Figure 3-1.

3.2.2 Pitch Control Rocket Motor Tests (Lockheed Propulsion Company)

3.2.2.1 Objective

Completion of the development program for the pitch control motor will verify the motor performance and assure the best motor component design. Igniter and motor-static firings will be used for ballistic performance analyses. A number of static firing tests are scheduled for demonstration of low and intermediate impulse pitch control motor performance. Environmental treatments imposed upon the test units prior to firing will help to firmly establish the motor design before qualification testing is attempted.

3.2.2.2 Test Plan

The pitch control motor development program will be initiated with a brief igniter development phase. Eight to ten igniters will be tested in free air and in simulated ignition volume chambers with explosive bridge wire initiators before motor static firings begin. Test firings with the hot wire igniter cartridges will include pellet basket firings and the last six development motor firings.

The motor development program is scheduled to encompass 28 test units. The first three motors will be conditioned to 70 F, 20 F, and 140 F, respectively, and then statically fired at ambient pressure. The primary test objective of these initial firings is motor ballistic performance evaluation of full total impulse motors.

Development motor No. T-4 will be test fired at 70 F under simulated altitude ignition conditions. Motor ignition under low ambient pressure will be verified by this firing.

The fifth motor will undergo 2-1/2 cycles of temperature cycling between -20 F and 140 F prior to static firing at 20 F and simulated altitude conditions. The temperature cycling test will demonstrate the ability of the propellant grain assembly to perform within NAA specification MC901-0002.

[redacted]

[redacted]

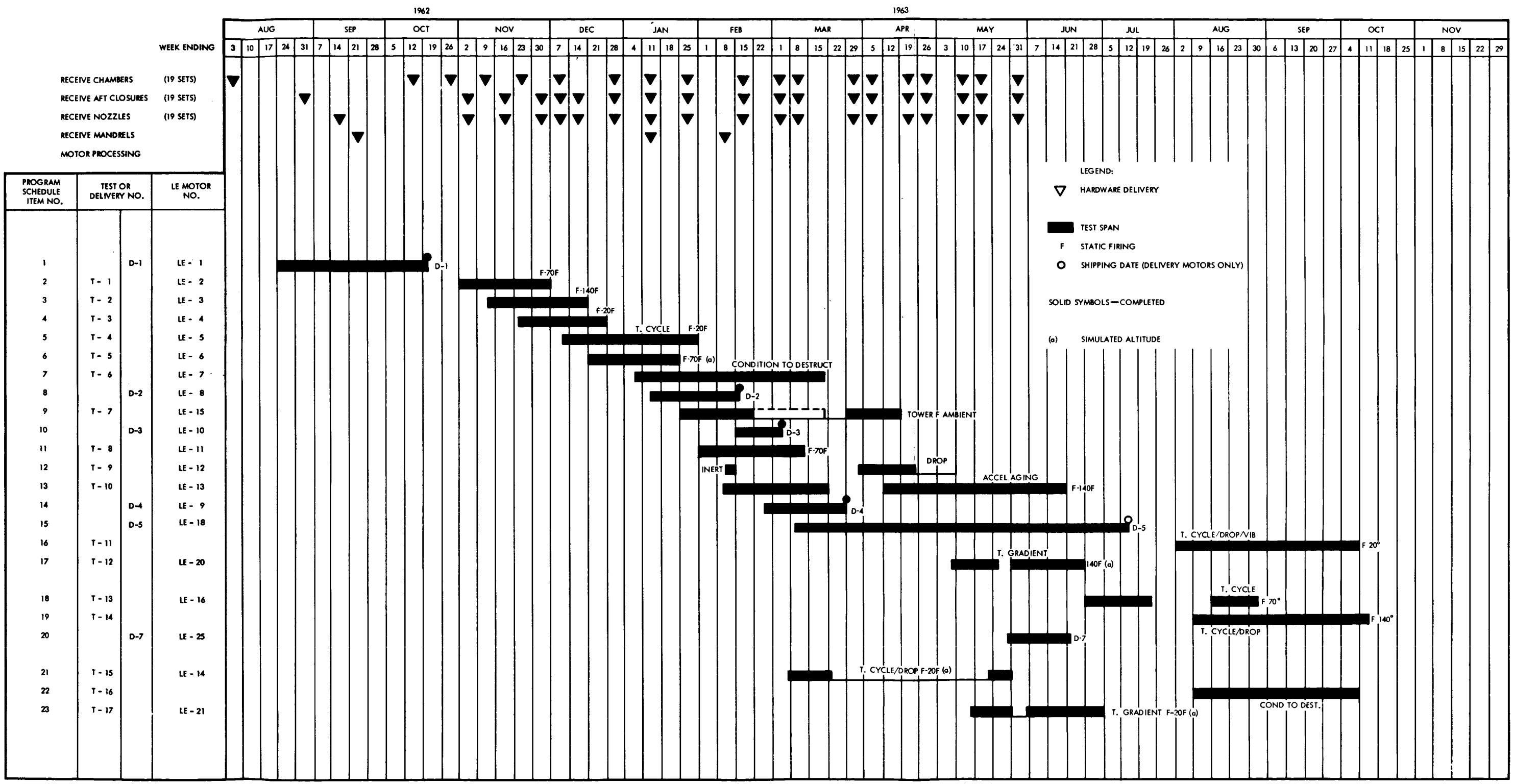


Figure 3-1. Apollo Launch Escape Motor Development Schedule

[redacted]

The sixth development motor will be a hydrotest of the empty case to verify the structural integrity.

Motor No. T-7 will be used for a grain safety margin demonstration test. The motor will be conditioned to successively lower temperatures from 20 F until grain structural failure occurs. Physical propellant properties data will be obtained from motor propellant grain instrumentation.

The subsequent three development units, motors eight through ten, will undergo 2-1/2 cycles of temperature cycling between -20 F and 140 F prior to static firing at 20 F, 140 F and 140 F, respectively, under simulated altitude ignition conditions.

The eleventh development motor will be utilized in the joint S&ID and Lockheed Propulsion Company ground test. The prime test objective is the structural evaluation of the launch escape system tower; however, pitch control motor firing data will be acquired by Lockheed and will furnish further ballistic performance information.

Motor No. T-12 will be test fired at ambient pressure after being conditioned to 140 F. This firing will be temperature cycled similar to T-5, T-8, T-9, and T-10 prior to firing.

Motor No. T-13 and T-14 will be vibration tested at 140 F and -20 F, respectively, prior to firing at 140 F and 20 F under simulated altitude ignition conditions. Vibration testing at the storage temperature extremes of the pitch control motor will impose a reasonable transportation and storage vibration environment and will allow subsequent motor performance analysis of the vibrated motors when fired.

Motor No. T-15 will be drop tested from a four-foot drop height to a solid surface on the head end, the nozzle end, and the side. The motor will be conditioned to -15 F prior to dropping. If the motor passes drop testing and is recoverable in a fireable condition, it will be statically tested after being conditioned to 140 F and under simulated altitude ignition conditions.

The next two motors, No. T-16 and T-17, will be tested in a ballistic centrifuge. A lateral acceleration of 19 ± 1 g will be imposed on the motors for a period of two minutes prior to firings at 140 F and 20 F respectively. This transverse (perpendicular to motor-thrust axis) acceleration portion of the environment is experienced by the pitch control motor during the atmospheric boost and abort phases of the Apollo mission.

Motor No. T-18 will undergo the same drop test as motor No. T-15, and then will be fired at 20 F and ambient pressure.

[redacted]

Two motors, No. T-19 and T-20, will be subjected to accelerated aging at 160 F for 75 days prior to static testing at 140 F and 20 F respectively. These units will be ignited under simulated altitude conditions. The aging program is designed to furnish motor performance data with respect to the five-years storage life requirement per NAA procurement specification MC467-0005.

Motor No. T-21 will undergo the same drop testing as motor No. T-15 and T-18 and then will be fired at 70 F and at a simulated altitude condition.

A low total impulse motor, No. T-22, will be fired at ambient pressure and at 70 F. This total impulse will be 1550 pound-seconds.

A temperature gradient test will be imposed on motor No. T-23 and T-24 before static firing. Motor No. T-23 will be conditioned to 140 F and then will be exposed to 20 F until the maximum attainable temperature gradient exists across the motor grain. At that time the motor will be fired. Motor No. T-24 will experience just the opposite gradient as motor No. T-23, and will be fired at 140 F. Both motors will be fired at ambient pressure. The ballistic effects of propellant temperature gradients will be determined from the motor firing data.

The pitch control motor development program will be concluded with three design freeze demonstration firings and one temperature cycle motor firing. Motor No. T-25, T-26, and T-27 will be fired at 140 F, 140 F, and 20 F respectively under simulated altitude ignition conditions. Motor T-25 will be tested in a ballistic centrifuge as were T-16 and T-17. Motor No. T-28 will be temperature cycled similar to units T-5, T-8, T-9, T-10, and T-12 and will be fired at ambient pressure and at 20 F.

3.2.2.3 Equipment

The test equipment utilized for the pitch control motor development program will include a single component thrust fixture, an instrumentation and data acquisition system, and temperature conditioning equipment. Hydrotest fixtures and equipment, vibration equipment, and vacuum equipment for the altitude ignition test will also be required.

3.2.2.4 Facilities

The pitch control motor development program will be performed at the existing facilities of the Lockheed Propulsion Company at the Redlands, California, plant.

3.3.2.5 Test Schedule

The schedule for the pitch control motor development program is shown in Figure 3-2.

[redacted]

MOTOR DESIGN COMPLETION
THRUST STAND DESIGN COMPLETION
TOOL DESIGN COMPLETION
TOOL FABRICATION COMPLETION
THRUST STAND COMPLETION
START FABRICATION
MOTOR PROCESSING

PROGRAM SCHEDULE ITEM NO.	TEST OR DELIVERY NO.		PC MOTOR NO.	TOTAL IMPULSE LB-SEC
1		D-1	PC - 1	
2	T - 1		PC - 2	3000
3	T - 2		PC - 3	3000
4	T - 3		PC - 4	3000
5	T - 4		PC - 5	3000
6	T - 5		PC - 6	3000
7	T - 6		PC - 7	3000
8	T - 7		PC - 8	3000
9	T - 8		PC - 9	3000
10		D-2	PC - 10	—
11	T - 9		PC - 37	1700
12	T - 10		PC - 12	3000
13	T - 11		PC - 17	1550
14		D-3	PC - 14	—
15		D-4	PC - 20	1700
16	T - 12		PC - 13	3000
17	T - 13		PC - 27	1700
18	T - 14		PC - 25	3000
19	T - 15		PC - 38	3000
20	T - 16		PC - 28	1700
21	T - 17		PC - 26	3000
22		D-5	PC - 19	1700
23	T - 18		PC - 30	1700
24	T - 19		PC - 23	1700
25	T - 20		PC - 24	3000
26	T - 21		PC - 32	1700
27	T - 22		PC - 18	1550
28	T - 23		PC - 21	1700
29		D-7	PC - 22	1700
30	T - 24		PC - 16	1700
31	T - 25		PC - 33	1700
32	T - 26		PC - 34	1700
33	T - 27		PC - 35	1700
34	T - 28		PC - 36	1700
35	T - 29		PC-39	

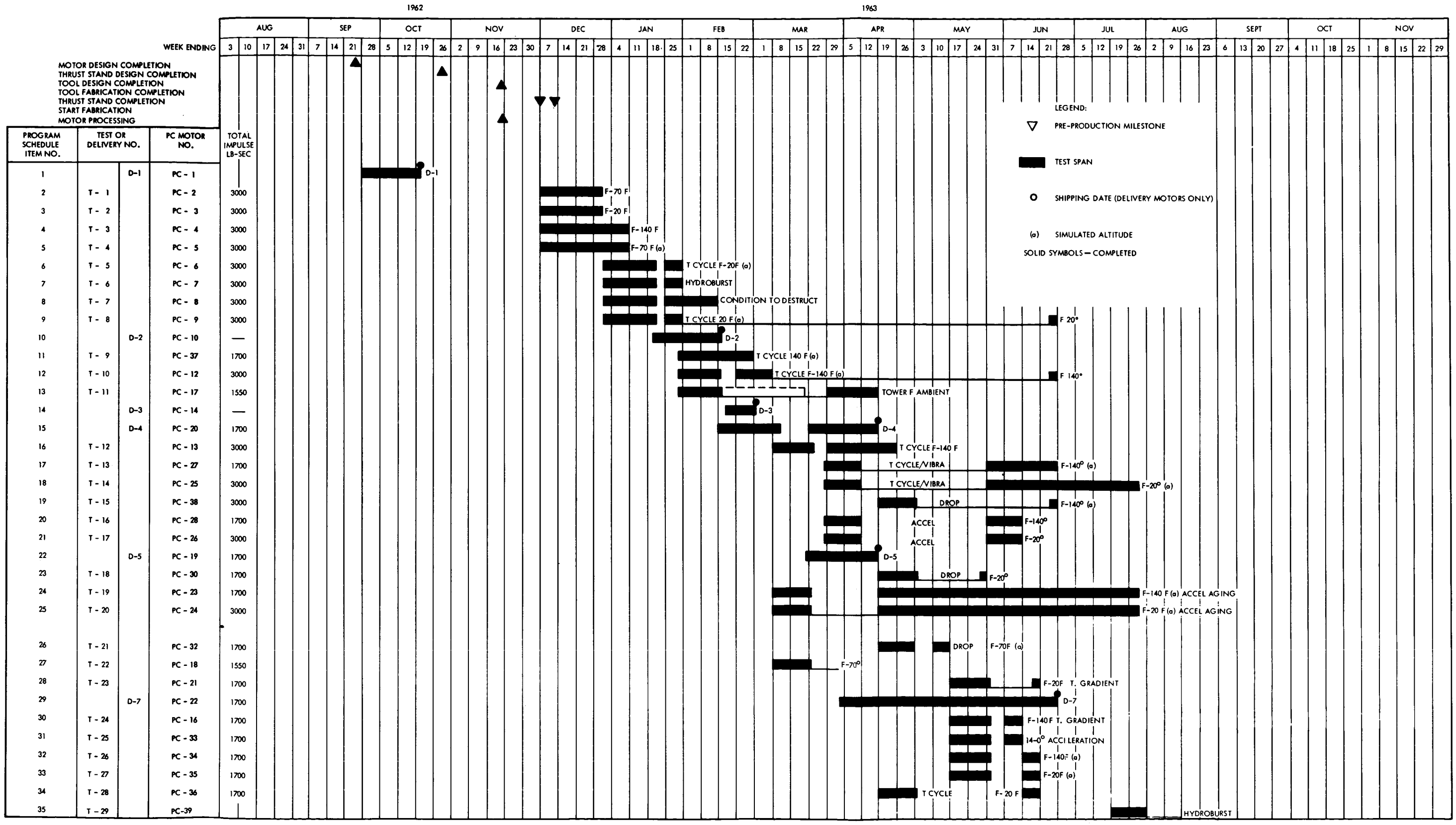


Figure 3-2. Apollo Pitch Control Motor Development Schedule

[redacted]

[redacted]

3.2.3 Tower Jettison Rocket Motor Tests (Thiokol Chemical Corporation)

3.2.3.1 Objective

The tower jettison motor will undergo a development program in order to dcmonstrate its ability to perform as required after having been subjected to various environmental treatment. Development testing will optimize component designs, identify design margins, and render the tower jettison motor in a finalized configuration for qualification testing.

3.2.3.2 Test Plan

The tower jettison motor development program consists of two parts; the igniter and the motor development programs.

Twenty-two open air igniter tests are scheduled for igniter development, ten of which will be tested using exploding bridge wire initiators prior to live motor firings. Four will be fired with hot wire initiators, and the remaining eight will be fired with hot wire igniter cartridges. The last seven development motors will be fired with hot wire igniter cartridges.

The tower jettison motor development program will be initiated with a motor firing at 70 F and at ambient pressure for propellant ballistics evaluation.

The second development unit will undergo packaged drop-testing and will be statically fired under the same conditions as motor No. 1.

Motor No. 3 will be subjected to accelerated aging at 160 F for 75 days and will be fired at 20 F and at ambient pressure.

Motors No. 4, 5, and 6 will be temperature cycled between -20 F and 140 F. Motor No. 4 will then be statically fired at 70 F at ambient pressure. In addition, motors No. 5 and 6 will receive packaged drop-testing prior to test firing at 20 F and 140 F, respectively, and at ambient pressure.

Motor No. 8 will be conditioned to 20 F, placed in the 140 F conditioning chamber, and fired when the maximum temperature gradient exists across the propellant grain.

Development motors No. 10 and 11 will be utilized in static testing at the Arnold Engineering Development Center in Tullahoma, Tennessee. The motors will be fired at 70 F and under a pressure environment simulating a minimum altitude of 100,000 feet. These tests will be performed in a three component thrust stand which will be instrumented to provide true thrust vector position data under altitude conditions.

[redacted]

[redacted]

Three additional ballistic verification motors are scheduled for static firing subsequent to AEDC testing. Motors No. 12, 13, and 14 will be test fired at 20 F, 140 F, and 20 F, respectively. The first two motors will be ignited under simulated altitude conditions.

A group of seven development motors, 15 through 21, will undergo vibration testing. Motor No. 15, 16, and 17 will be test fired at 70 F, 140 F, and 20 F, respectively. Motor No. 15 and 19 will be ignited under simulated altitude conditions. Motor No. 18, 19, and 20 will be temperature cycled and package dropped prior to static test at 70 F, 140 F, and 20 F, respectively. In addition, motor No. 20 will be fired while a temperature gradient exists across the grain. Motor AD-21 will be fired at 70°F.

Motors No. 22 and 23 will be static tested at 140 F after package drop testing. Motor No. 22 will be ignited under simulated altitude conditions.

The tower jettison motor development program will be concluded with motor AD-24. This motor, a ballistic verification motor, will be fired at a temperature of 70°F.

3.2.3.3 Equipment

Test equipment utilized in the tower jettison motor development program will include two three-component thrust stands, instrumentation and data acquisition systems, temperature conditioning equipment, and vibration equipment. Hydrotest equipment, vacuum equipment for simulated altitude ignition testing, and motor handling equipment will also be used.

3.2.3.4 Facilities

The tower jettison motor development program will be conducted at the existing facilities of the Thiokol Chemical Corporation at the Elkton, Maryland, plant. The support of the Arnold Engineering Development Center simulated altitude facilities will be required for two development tests.

3.2.3.5 Test Schedule

The subcontractor's schedule for the tower jettison motor development program is shown in Figure 3-3.

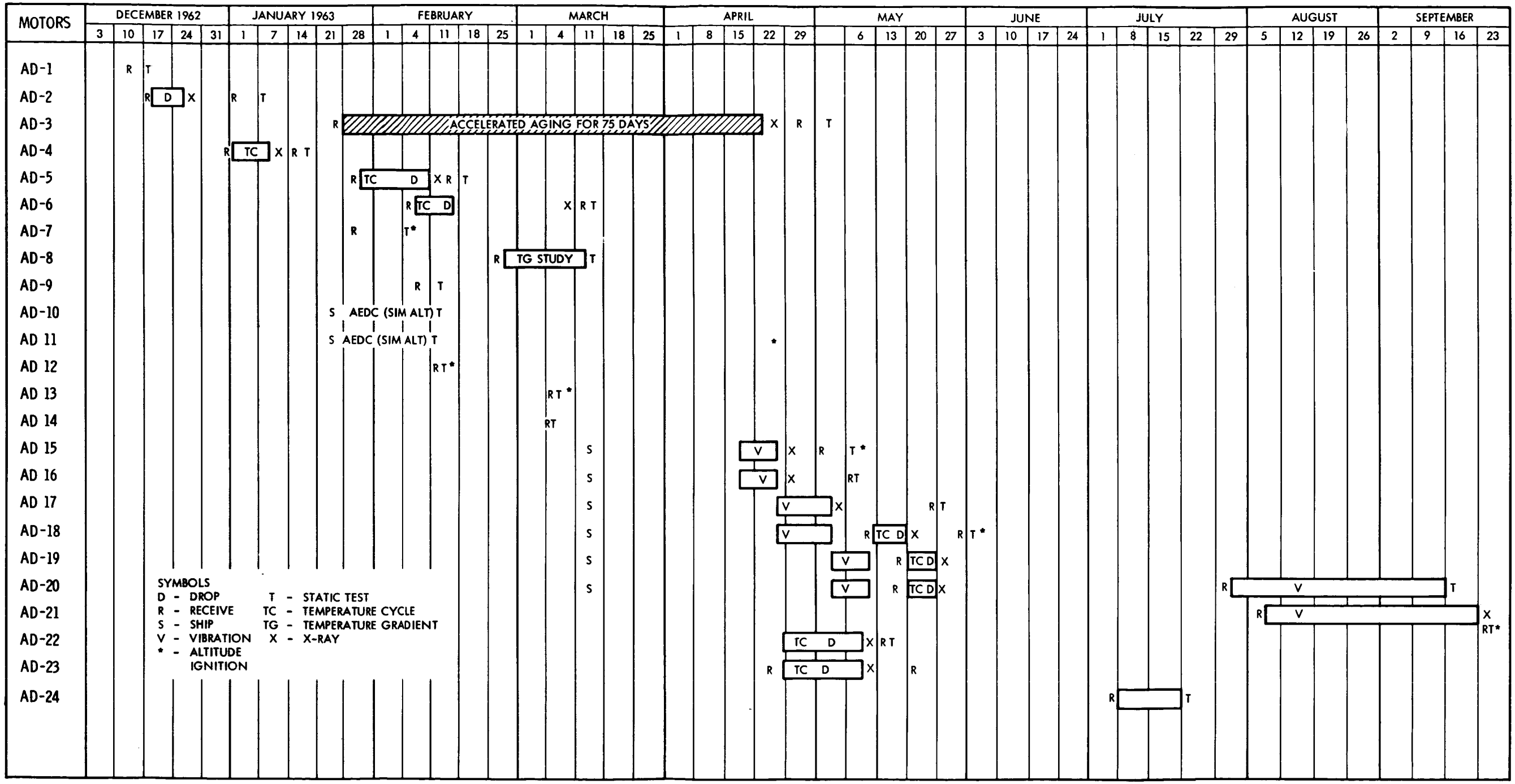


Figure 3-3. Apollo Tower Jettison Motor Development Schedule

4.0 EARTH LANDING SYSTEM

4.1 SCOPE

This section describes engineering development tests to be conducted by Northrop-Ventura and S&ID. Northrop-Ventura will be responsible for the design and development test of the parachutes and parachute deployment subsystems. S&ID will be responsible for the development test program of the crew shock-attenuation subsystems. The objective of these tests is to develop a system which will mitigate the transient deceleration loads due to earth-landing impact and which will insure safety for the crew, structure, and equipment.

Qualification and reliability tests will be covered in Volume III.

4.2 SUBCONTRACTOR TEST PLAN (NORTHROP-VENTURA)

4.2.1 Parachute Subsystem Tests

4.2.1.1 Objective

The objective of this test program is to develop and prequalify the parachute subsystem for Apollo per S&ID Procurement Specification MC 901-0001.

4.2.1.2 Test Plan

This plan is basically divided into two categories, laboratory testing and aerial drop testing.

Each of these categories is in turn divided into development and prequalification phases.

4.2.1.2.1 Laboratory Development Tests. The development phase of the laboratory testing consists of tests on materials, components, and circuits used in parachutes, parachute disconnects, parachute mortars, and sequence control units to (a) determine their application suitability, (b) acquire design or process information, and (c) develop assurance that the product will successfully complete the prequalification phase.

[redacted]

4. 2. 1. 2. 2 Laboratory Qualification Tests. The qualification phase of the laboratory testing includes design proof tests and mission life tests. The former consist of tests for (a) climatics, (b) electromagnetic interference and explosion proofing, (c) prelaunch environments (static firing), and (d) sequentially applied maximum mission environments, followed by tests to failure for verification of critical environmental and functional design margins. Mission life tests consist of exposure to single or combined mission environments employing nominal values of expected environmental stresses.

4. 2. 1. 2. 3 Aerial Drop Development Tests. The development phase of the aerial drop testing consists of 10 tests on drogue parachutes, 24 individual main parachutes, 19 clustered main parachutes, and finally on the complete system for design verification purposes. A total of approximately 69 drops are scheduled, including 16 complete system tests employing boilerplates 3 and 19. Data to be obtained consists of parachute force versus time; position versus time; temperature, barometric pressure, and winds versus altitude; and motion picture coverage to include ground-to-air, air-to-air, and a camera on board the drop vehicle. These data will be used to verify that design objectives are being met or to guide the appropriate corrective action.

4. 2. 1. 2. 4 Aerial Drop Prequalification Tests. The prequalification phase of the aerial drop testing consists of approximately 16 drops of boilerplates 3 and 19, including simulation of operational extremes anticipated for normal entry and mission abort conditions. Data requirements are the same as for paragraph 4. 2. 1. 2. 3.

4. 2. 1. 3 Equipment

RB-66 and C-130 aircraft, from the 6511th Test Group (Parachute), at El Centro, will normally be used for dropping simple weight bombs and specially constructed parachute test vehicles which simulate the Apollo parachute compartment.

A specially modified C-133A aircraft, operated by the Douglas Aircraft Company, will be used for dropping the Apollo boilerplates.

Equipment at the drop test range includes: cinetheodolite stations, tracking radar, a Rawin system for determining atmospheric conditions from ground to drop altitude, and a data telemetering system.

4. 2. 1. 4 Facilities

Laboratory tests will be performed at the existing facilities of the Northrop-Ventura Corporation, at Newbury Park, California. Aerial drop

[redacted]

tests will be performed at the Department of Defense Joint Parachute Test Facility, Naval Air Facility, El Centro, California. Existing government facilities at El Centro, including an extensively equipped drop-test range, will be supplemented as required by Northrop-Ventura and S&ID.

4.2.1.5 Test Schedule

The schedule for the aerial drop test program is presented in Figure 4-1.

4.3 S&ID TESTS

4.3.1 One-Tenth Scale Model Water Landing and Flotation Test

4.3.1.1 Objectives

Phase A - Obtain preliminary data, in advance of boilerplate tests, on water landing accelerations and stability envelopes using parameters of horizontal and vertical landing velocities and C/M attitudes.

Phase B - Determine flotation, statical and dynamic stability characteristics for intact and damaged cases considering various weights, C.G. locations and simulated sea state using a scaled model vehicle and a model test basin.

4.3.1.2 Test Plan

Phase A - Horizontal velocity is to be applied in increments of five feet per second, from zero velocity until instability (tipping) occurs, with all combinations of the landing parameters in calm water and in a simulated sea state.

Phase B - The following operations will constitute the flotation test plan:

1. Flotation test
2. Statical stability test
3. Dynamic test

From static tests determine static stable positions, range of stability and curves of righting arms and moments.

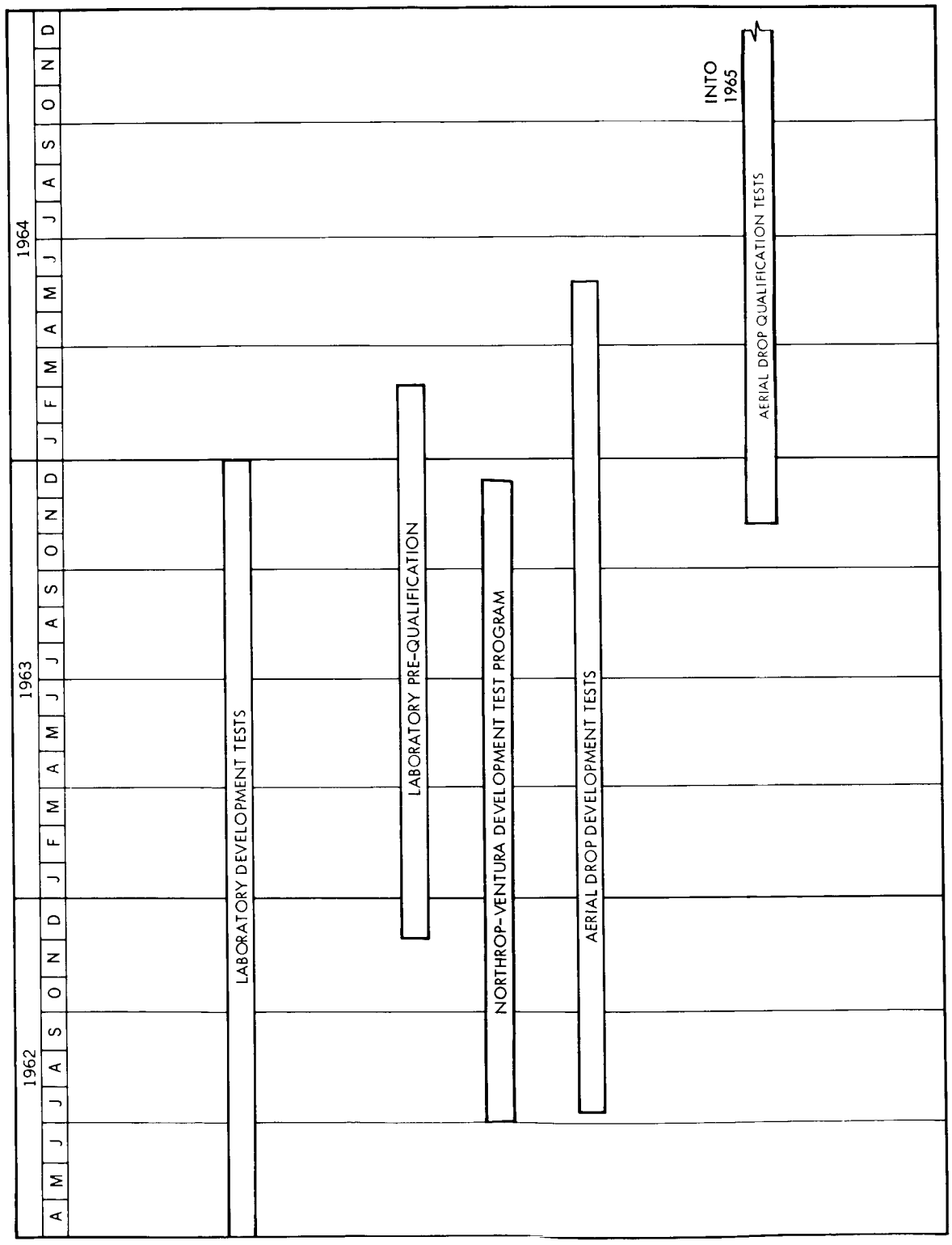


Figure 4-1. Parachute Subsystem Test Schedule

[redacted]

From dynamic tests determine:

1. Vehicle response in a sea state of four in each stable attitude.
2. Probability of capsizing in various sea states for each stable attitude.
3. Severity of motion
4. Measurement of drift
5. Motion pictures of vehicle motion
6. Damping action of vehicle

4. 3. 1. 3 Equipment

The equipment necessary for the tests is:

1. Floodable 1/10 scale model of C/M
2. Wave state simulator
3. Force-stroke measuring devices
4. One set of biaxial linear accelerometers
5. Oscillographic recording equipment
6. High-speed motion picture coverage

4. 3. 1. 4 Facilities

The S&ID Space Sciences Lab hydrodynamic towing channel will be used to conduct the test.

4. 3. 1. 5 Test Schedule

Phase A - A preliminary portion of Phase A was completed 1 July 1963.

Phase B - Will be completed by 1 November 1963.

[redacted]

5.0 ENVIRONMENTAL CONTROL SYSTEM*

5.1 SCOPE

This section presents an outline of the environmental control system (ECS) design verification and development evaluation tests to be accomplished during Apollo spacecraft development. In order to keep the crew and equipment operating at top efficiency, it is essential that the characteristics of the surrounding atmosphere, including temperature and pressure, be controlled. Test of the ECS will ensure adequate temperature, humidity, oxygen, and pressure control; equipment cooling; and removal of carbon dioxide, toxic gases, and other contaminants. Food, water, waste management, personal hygiene, and crew protection equipment will be developed and evaluated from a mechanical standpoint by means of the ECS breadboard tests.

There are several modes of operation of the ECS for the Apollo vehicle in the command or service module. These modes will be tested separately and in combination, in order to optimize the design and to assure complete reliability of the over-all system.

Testing of the ECS by the subcontractor (AiResearch Manufacturing Company, Los Angeles, California), and of the cryogenic storage subsystem by the subcontractor (Beech Aircraft Corp., Boulder, Colo.), will be accomplished at four levels: materials, components, subsystems, and system. After testing has established the satisfactory performance of the development components and subsystems at the system level, the designs of the components and subsystems will be optimized to spacecraft status with respect to weight, materials, and finishes.

Materials will be investigated by the subcontractors for their integrity and reliability in Apollo environments. Off-the-shelf components will be tested to confirm performance or to determine design modifications. Newly designed components will be tested to verify design concepts or improvements. Testing of these components will continue until nominal performance requirements are met in selected critical environments.

Performance of the subsystems will be optimized through design changes resulting from tests that are calculated to determine the interactions of the components and the influence of the connecting media.

*Entire section reissued

[redacted]

Performance of the system will be optimized through design changes resulting from tests calculated to determine the interaction of the subsystem and the influence of the connecting ducts and tubing.

The prime contractor (S&ID) will perform an integrated system test on a breadboard ECS.

Three major tests programs will be conducted at the prime contractor facilities. These will consist of an integrated ECS breadboard test, radiator development test, and coldplate test program.

The integrated ECS breadboard test will consist of a complete ECS installed in a pressure vessel having the same internal volume as the spacecraft. The operational characteristics of the system will be monitored during simulated Apollo mission phases.

The ECS radiator test program will consist of placing a thermal coated radiator in a vacuum chamber and evaluating its operational performance during simulated Apollo mission environments.

The coldplate test program will be initiated by performing development type tests on a single coldplate configuration. Upon performance verification a complete ECS network will be assembled in a test fixture simulating the spacecraft structure. The assembled coldplate network will be placed in a vacuum chamber and subjected to a mission profile, simulating time, mission environments, and the electronic equipment heat loads. After demonstrating mission capability, the network will be integrated into the water-glycol subsystem of the ECS breadboard to evaluate and demonstrate integrated system capability.

5.2 SUBCONTRACTOR TEST PLAN (AiResearch)

The subcontractor shall be responsible for the accomplishment of the complete development test program on the environmental control system equipment supplied by the subcontractor. All testing shall be monitored by S&ID.

5.2.1 ECS-GSE Integrated System Development Test

5.2.1.1 Objective

The objective is to determine and optimized the operational performance of ECS and GSE when integrated and tested under simulated count-down conditions.

[redacted]

5.2.1.2 Test Plan

The ECS test procedures will be designed to evaluate the GSE during the conditions encountered during ECS ground operations. Tests will contribute to instrumentation locations and checkout procedures used in spacecraft.

5.2.1.3 Equipment

Calibrated laboratory instrumentation shall be used to monitor system performance.

5.2.1.4 Facilities

Testing will be performed at AiResearch's Los Angeles facility.

5.2.2 ECS System Development Test

5.2.2.1 Objective

The objective is to determine and optimize the performance of an environmental control system complying with the requirements of S&ID procurement specification MC 999-0034.

5.2.2.2 Test Plan

A complete ECS, except for the entry oxygen package, shall be subjected to simulated prelaunch, launch, translunar coast, lunar orbit, entry, and emergency modes of the Apollo lunar mission. Calibrated laboratory equipment shall be used to monitor system performance. The C/M thermal loads, C/M equipment locations, C/M tubing installations, space radiators, electrical installations, electrical power system, supercritical fluid system, and fuel cell water production will be simulated.

5.2.2.3 Equipment

Testing will be performed in an altitude chamber. The chamber will be limited to 1.0 psia command-module-interior minimum pressure. A high-vacuum unit shall provide a vacuum source for evaporator operations.

5.2.2.4 Facilities

Testing shall be performed at the AiResearch Los Angeles facilities.

5.2.3 ECS Subsystem Development Tests

5.2.3.1 Objective

The objective is to determine and optimize the functional and physical configurations of the subsystems required to develop an environmental control system complying with the requirments of S&ID Procurement Specification MC 999-0034.

5.2.3.2 Test Plan

5.2.3.2.1 Water-Glycol Subystem. A water-glycol subsystem and the temperature control components of the cabin temperature control subsystem will be installed in an altitude chamber with simulated suit, cabin, and electronic thermal loads. The tubing installation pressure drops and space radiators will also be simulated. Test runs will be made at laboratory ambient and 5.0 psia pressures with thermal loads varied through a range of -10 percent to +10 percent of analytically predicted values. Subsystem performance will be determined quantitatively. Some areas of specific interest are response time of the temperature control circuits and pump performance.

5.2.3.2.2 Entry Oxygen Subsystem Test. Subsystem characteristics during all mission phases and performance during entry will be determined and optimized.

5.2.3.2.3 Pressure Suit Circuit Subsystem Tests. The suit circuit subsystem will be installed in a vacuum chamber and tested at 5.0 psia and laboratory ambient. Suit pressure drop and crew metabolic rate will be simulated with a metabolic stimuli generator. The suit circuit performance will be determined quantitatively with the interface parameters maintained at analytically predicted values and with the analytically predicted values varied ±10 percent.

The objective of this test is to evaluate and optimize component performance for subsystem operation.

5.2.3.3 Equipment

Equipment	Usage
Dynamic recording systems	All phases
Signal conditioning system	All phases
Water-glycol supply cart	All phases
High-vacuum and condenser unit	All phases
Metabolic simulator	All phases (Suit circuit)
Contaminate analyzer	All phases
System vacuum fixture	All phases
Thermal load simulators	All phases
Portable system tester and signal conditioning system	System and integrated system test

5.2.3.4 Facilities

Water-glycol subsystem tests will be performed at AiResearch's Los Angeles facilities. The entry oxygen subsystem will be tested at the Boron, California, facilities of AiResearch.

5.2.3.5 Test Schedule

The test schedule for the subcontractor test plan is shown in Figure 5-1.

5.3 S&ID TEST PLAN

5.3.1 ECS Integrated System (Breadboard) Test

5.3.1.1 Objectives

The Apollo environmental control system breadboard tests are to be conducted to study and evaluate the ECS as an integrated unit. The ECS will be installed in the spacecraft location in a pressure vessel having the same internal volume as the spacecraft. The test will be conducted in a vacuum chamber and will simulate prelaunch, launch, earth orbit, trans-lunar coast, lunar orbit, reentry, and postlanding phases of the Apollo mission. Emergency conditions such as a micrometeorite puncture will also be simulated. The results of these tests will produce an integrated ECS that will meet design requirements.

The breadboard system will also be used for verifying the performance of new components and subsystems resulting from design improvements or changes in system performance requirements.

The ECS breadboard test program will support the development of the ECS and provide data to prove design concepts by evaluation of individual components, subsystems, systems, integrated systems and their interactions.

Testing will be performed to demonstrate system capability to provide a conditioned atmosphere for pressure-suit operation.

Testing will be performed to demonstrate system capability to provide a shirtsleeve environment for the command module.

Testing will be performed to determine system out-gassing and demonstrate system capability in removal of toxic atmospheric constituents. A gas analyzer will be utilized to monitor the command module atmosphere.

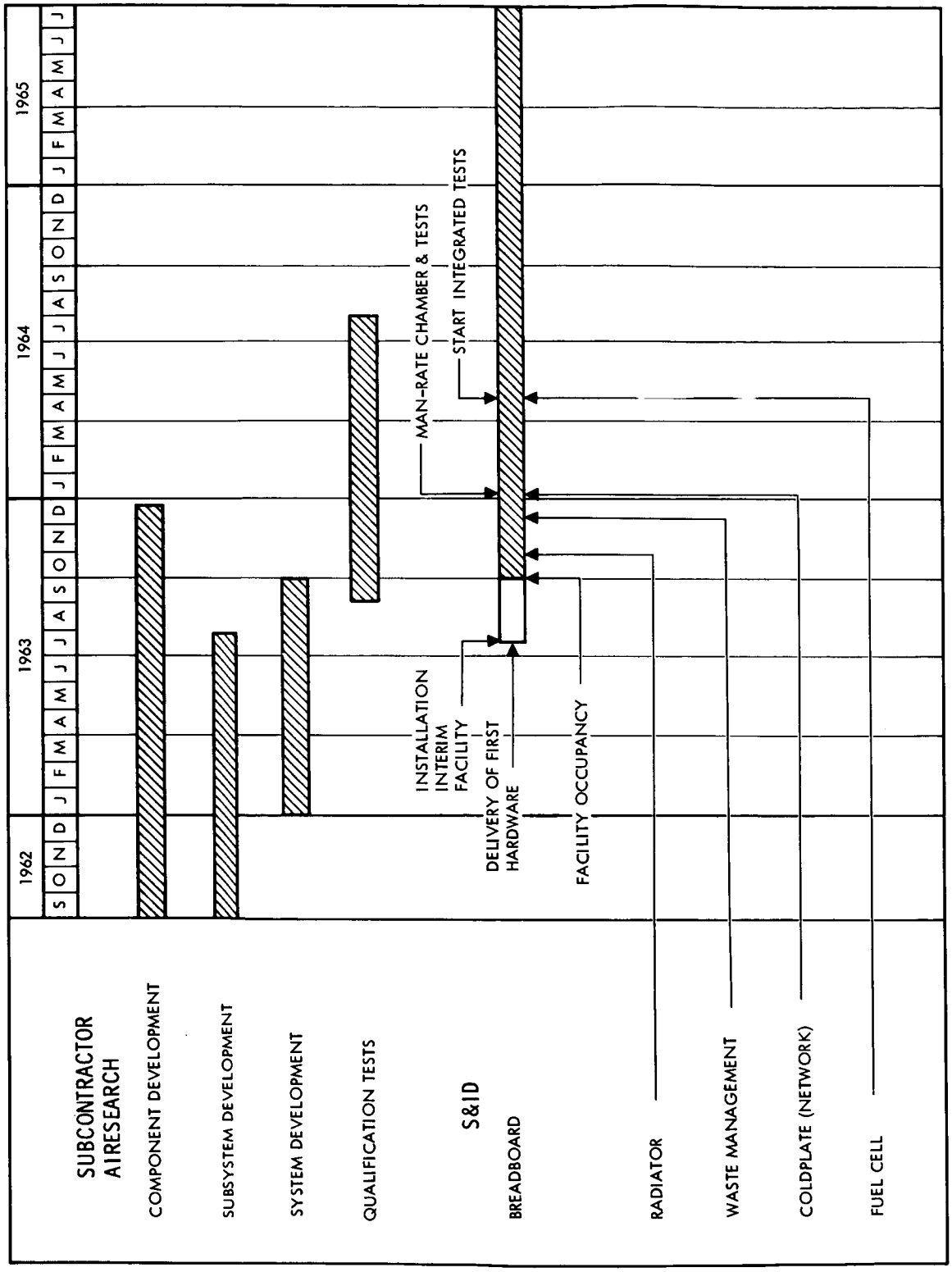


Figure 5-1. Environmental Control System Test Schedule

Testing will be performed to demonstrate system capability to provide thermal control to the required equipment in the command and service modules.

Testing will be performed to demonstrate the system capability of providing a habitable environment with component failure and/or emergency conditions imposed on it by design requirements.

5.3.1.2 Test Plan

A pressure vessel, or environmental simulator, having the same interior geometry as the spacecraft command module, with the C/M components installed in their spacecraft location, will be tested in the altitude chamber. The test parameters imposed will (1) subject the system equipment to the design parameters to develop an integrated environmental control system and (2) demonstrate environmental control system capability to meet design requirements. These parameters will include all Apollo mission phases.

The equipment installed in the command module will be the first tested with the interface equipment simulated and operating within the system parameters. The simulating equipment will be replaced as the interface units become available, thus integrating a complete environmental control system with electrical power and cryogenic interfaces with the fuel cell. The integrated system will be operated through a complete Apollo mission, including all modes.

Command module crew compartment pressure control will be tested through the complete simulated mission of four test phases. Cabin pressure at prelaunch and launch will be 14.7 to 5.0 psia, including the time rate change. Cabin pressure during the flight phase will be monitored for normal maintenance of 5.0 psi with simulated continuous inherent command module leakage of 0.2 pounds of gas per hour during a 14-day mission.

Tests will be conducted to verify the pressure control system maintenance of 5.0 to 3.5 psia during a simulated puncture of the spacecraft for a minimum of 5 minutes. The puncture will be simulated by a one half inch orifice solenoid valve.

The pressure suit system demand regulator will be tested during emergency operation for maintenance of 3.5 psia, while the cabin is at 1×10^{-4} Torr vacuum and all systems operating. They must have the capability to operate continuously in this environment for a four-day period. The cabin fan will not be operating during vacuum conditions and, therefore, does not have to meet these requirements.

The breadboard test facility will be man-rated, and tests will be conducted to verify the capability of the ECS to provide a habitable environment for three crew members during a 14-day simulated Apollo mission. An airlock will be utilized for rescue operations. Crew protection will be provided at all times by monitoring the crew performance and C/M interior with TV cameras, by maintaining audio contact, and by using biomedical instrumentation.

The following parameters will be monitored during human occupancy tests to verify system performance:

1. Oxygen supply
2. Carbon dioxide removal
3. Water removal
4. Temperature and pressure control
5. System leakage
6. Manual overrides, controls, and redundancies
7. IFTS - controls and displays
8. Food storage and preparation
9. Fecal storage
10. Urine disposal

5.3.1.2.1 Requirements. The breadboard test requirements are:

Pressure	
C/M external	Atmospheric to 1×10^{-4} Torr
C/M internal	Atmospheric to 1×10^{-4} Torr
Rate of change	Apollo launch profile
Temperature	
C/M interior wall	70 to 120 F (reentry)
Thermal loads	
External C/M	-430 Btu/hr to +1200 Btu/hr (not including reentry)

Metabolic load

Three men (shirt sleeve)	at rest and active
Three men (pressure suit)	at rest and active

Space radiator heat sink

Heat absorption rate	10,000 Btu/hr

Type of transmission

Radiate only at pressure	1×10^{-4} Torr

5.3.1.3 Equipment

A pressure vessel having the same internal volume as the spacecraft is required to house the breadboard system. Heating equipment with adequate controls is required for simulation of the thermal energy generated by spacecraft equipment, other than the ECS. A metabolic simulator is needed to provide a three-man metabolic load on the ECS. The simulator is to provide for any combination of men in/out suits.

An interim cryogenic storage system simulator is to provide 900 ± 25 psia oxygen at a maximum rate of 40.2 lb/hr flow to the oxygen pressure regulators. An interim power supply is to be furnished to simulate the fuel cell and inverters.

Additional support equipment will be required for the human occupancy test. (See Figure 5-2) The test capsule will be designed for a ΔP of 52 psi. Quick-opening hatches will be provided for the test capsule and the altitude chamber. An airlock will be utilized and will be maintained at 5 psi during manned test. An auxiliary air supply will provide rapid repressurization of the test capsule, airlock, and chamber. An auxiliary oxygen supply to the test capsule also will be available. Continuous monitoring of the crew will be provided by audio, visual (TV cameras), and biomedical instrumentation. Fail-safe and manual overrides will be installed on all critical equipment.

Fire protection of the crew members will necessitate the use of non-arcing or sealed electrical and electronic equipment. Electrical overloading protection and emergency electrical power shut-off to test capsule will be provided. A nitrogen purge to the test capsule will be a standby feature.

5.3.1.3.1 Power Requirements. Power source requirements are:

1. 115 volts, 3 phase, 400-cycle wye power

2. 28 volts, dc, power

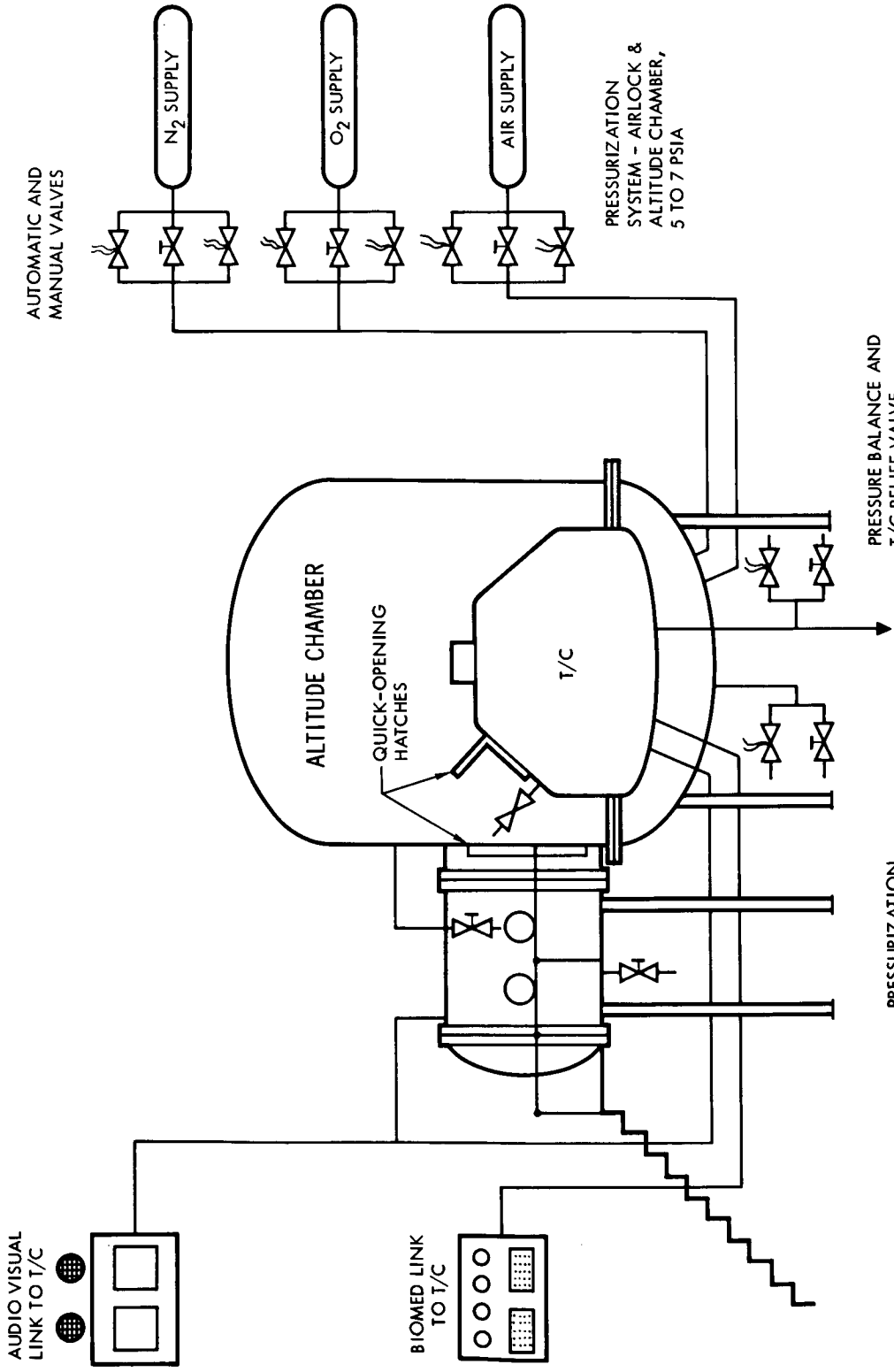


Figure 5-2. Proposed Man-Rated ECS Test Facility

An interim space radiator simulator with a heat absorption rate of 14,000 Btu/hr is required. A pump is to be supplied with a capacity of 200 ± 10 lb/hr and with an outlet pressure of 66 ± 10 psia maximum. The outlet temperature variation is from +45 F to a -30 F with an inlet temperature of +140 F maximum.

A nitrogen supply system is required to provide dry nitrogen for purging and leakage testing the environmental control system, cryogenic system, and the command module. The pressure requirements are 7500 psig for the oxygen reentry, 900 psi for the cryogenic oxygen, 250 psi for the hydrogen, 100 psig for the oxygen regulator, and 9 psig for C/M.

A thermal energy absorber is required that will absorb the radiant thermal energy load of space radiators in an ambient pressure of 1×10^{-4} Torr. The energy exchange rate is 10,000 Btu/hr maximum. Thermal equipment with adequate controls will be used to simulate the reentry thermal load and the associated internal zoned wall temperatures. The maximum wall temperature is 125 F.

5.3.1.4 Facilities

An altitude or vacuum chamber is required in which the environmental simulator (including the breadboard system), space radiator, and cold plates are to be tested at each of the Apollo mission modes. The facility is to be suitable for tests involving human occupancy.

A vacuum pumping system is required to supply the pressure equivalents for the mission flight simulation. The required pressures range from ambient atmospheric to 0.11 psia under dynamic conditions and 1×10^{-4} Torr under static conditions. The pumping system is to be capable of providing a pressure proportioned to the time profile of the Apollo launch and is illustrated in Figure 5-3.

An area is required to house the altitude (vacuum) chamber, instrumentation, controls, pumping system, interface simulators, and a data-collecting system. (See Figure 5-4.)

5.3.1.5 Test Schedules

The integrated breadboard system test schedule is shown in Figure 5-1.

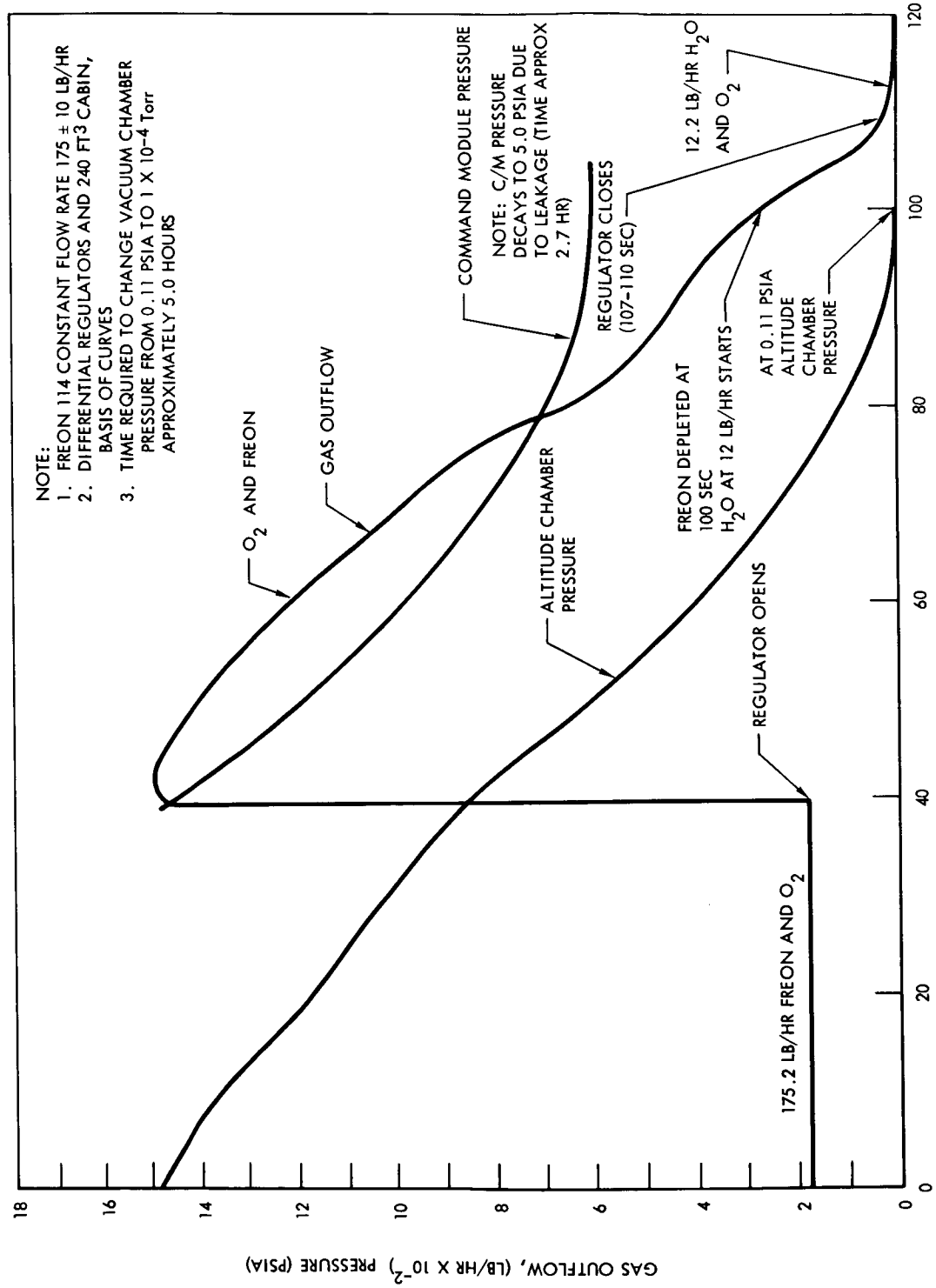


Figure 5-3. Apollo Launch Profile-Vacuum Chamber Gas and H_2O Loads

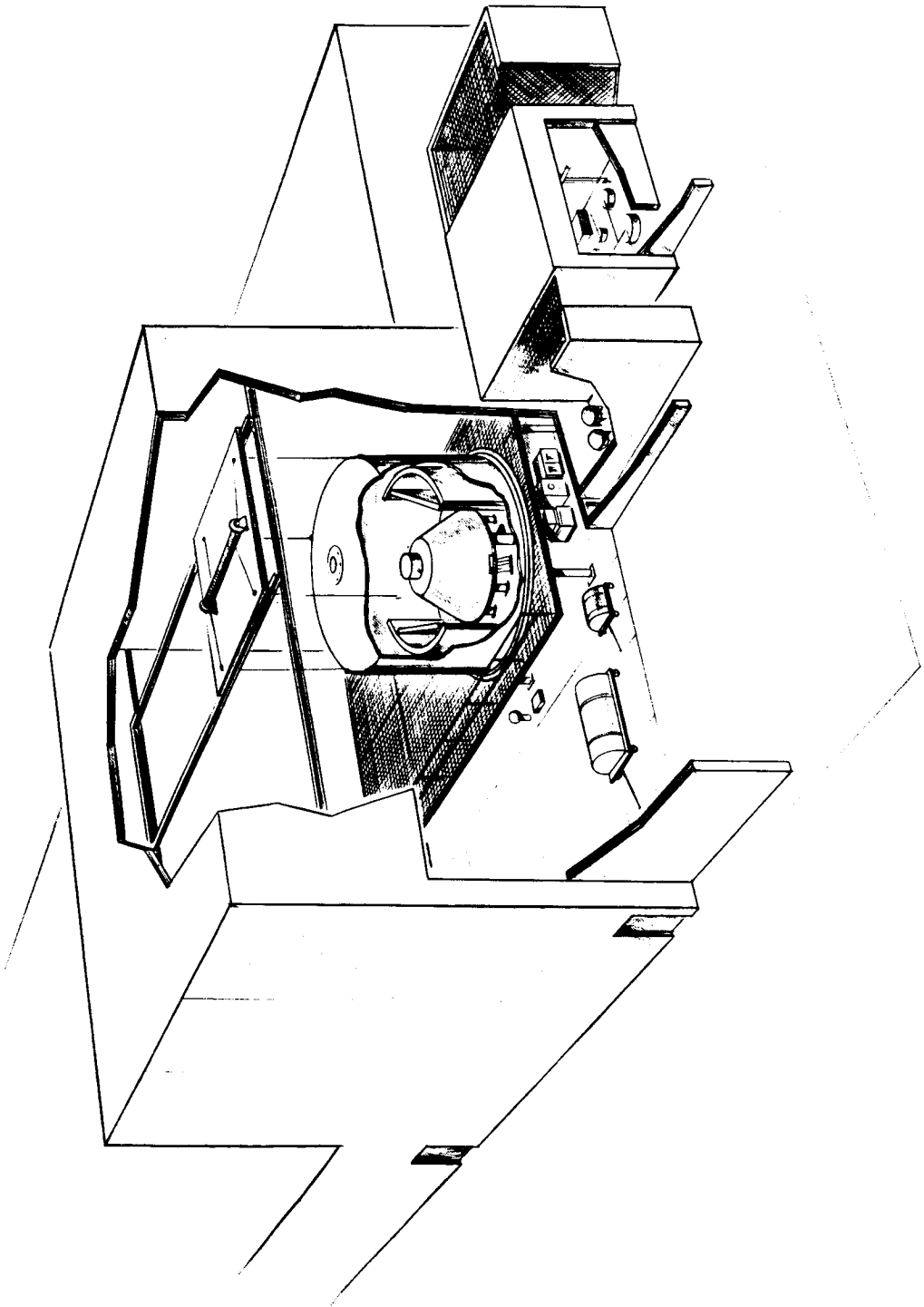


Figure 5-4. Proposed Facility—Integrated (Breadboard) Environmental Control System Test Program

[redacted]

5.3.2 Radiator Test Plan

5.3.2.1 Objective

The Apollo ECS radiator test program will be conducted at S&ID facilities. The panels will be subjected to natural (climatic) and induced environmental conditions to verify design requirements during installation, transportation, handling, storage, and simulated Apollo mission profiles.

5.3.2.2. Test Plan

The test plan will be divided into two programs: the development program and the qualification program. Each program will specify the test requirements desired and the method to be used for testing radiator panels.

Tests will evaluate and demonstrate the capability of the ECS radiator panels to provide a water-glycol heat dissipator for the thermal loads generated in the command and service modules during the various Apollo mission environments. (Ref. Figure 5-5, 60 sq ft radiators for typical lunar orbital mission.)

5.3.2.3 Test Requirements

1. Determine the ΔP of water-glycol solution through the radiator tubing under various flow rates and temperatures.

2. Determine equilibrium temperature of the radiator in the space chamber, using coolant flow rates that simulate Apollo mission environmental conditions.

3. Determine the effect of an unbalanced coolant upon two parallel panels.

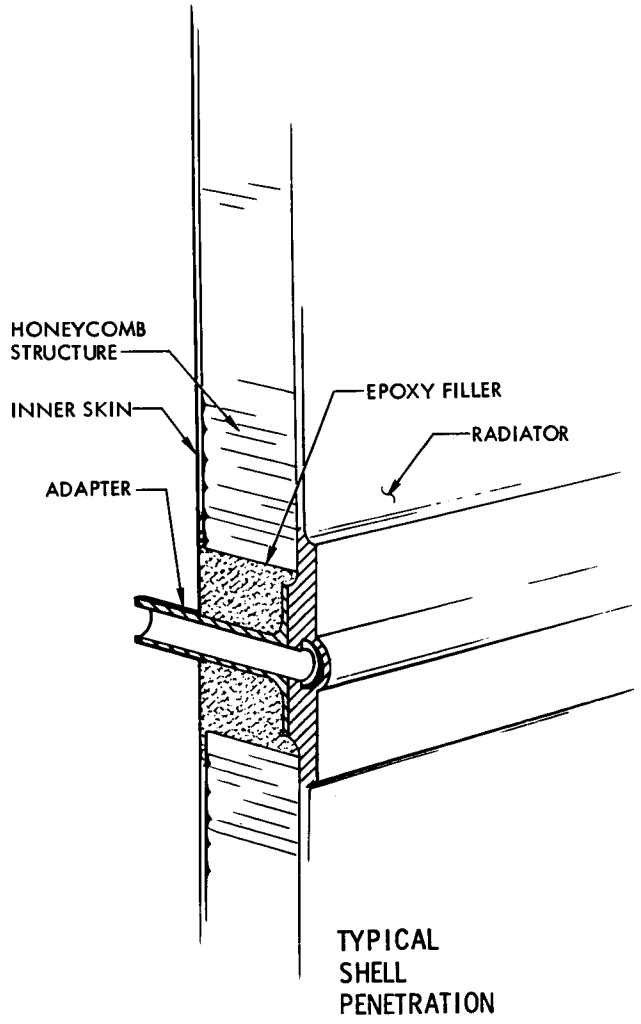
4. Determine the temperature transients with sudden changes in external and internal loads.

5. Determine temperature gradient along fin and tubing versus coolant flow rate.

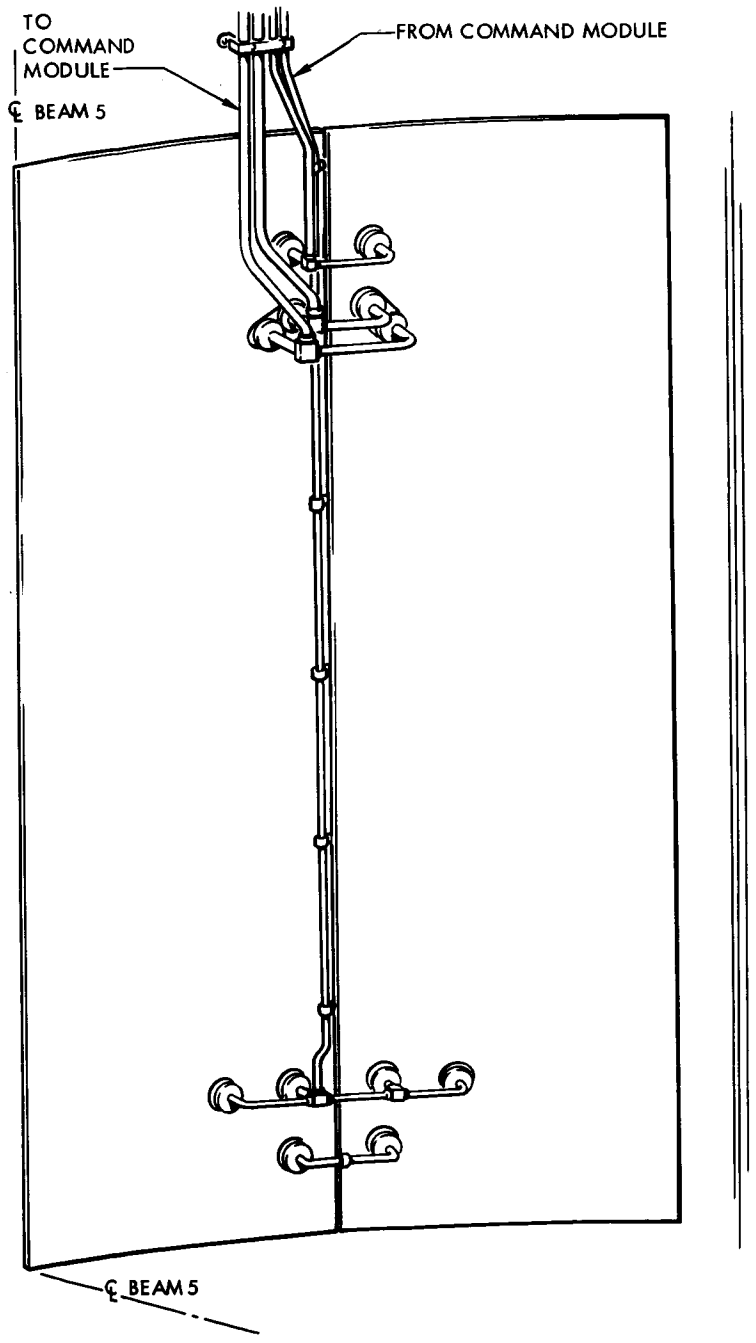
6. Determine effects of freezing glycol in radiator.

7. Determine effects of venting water-glycol from the radiator.

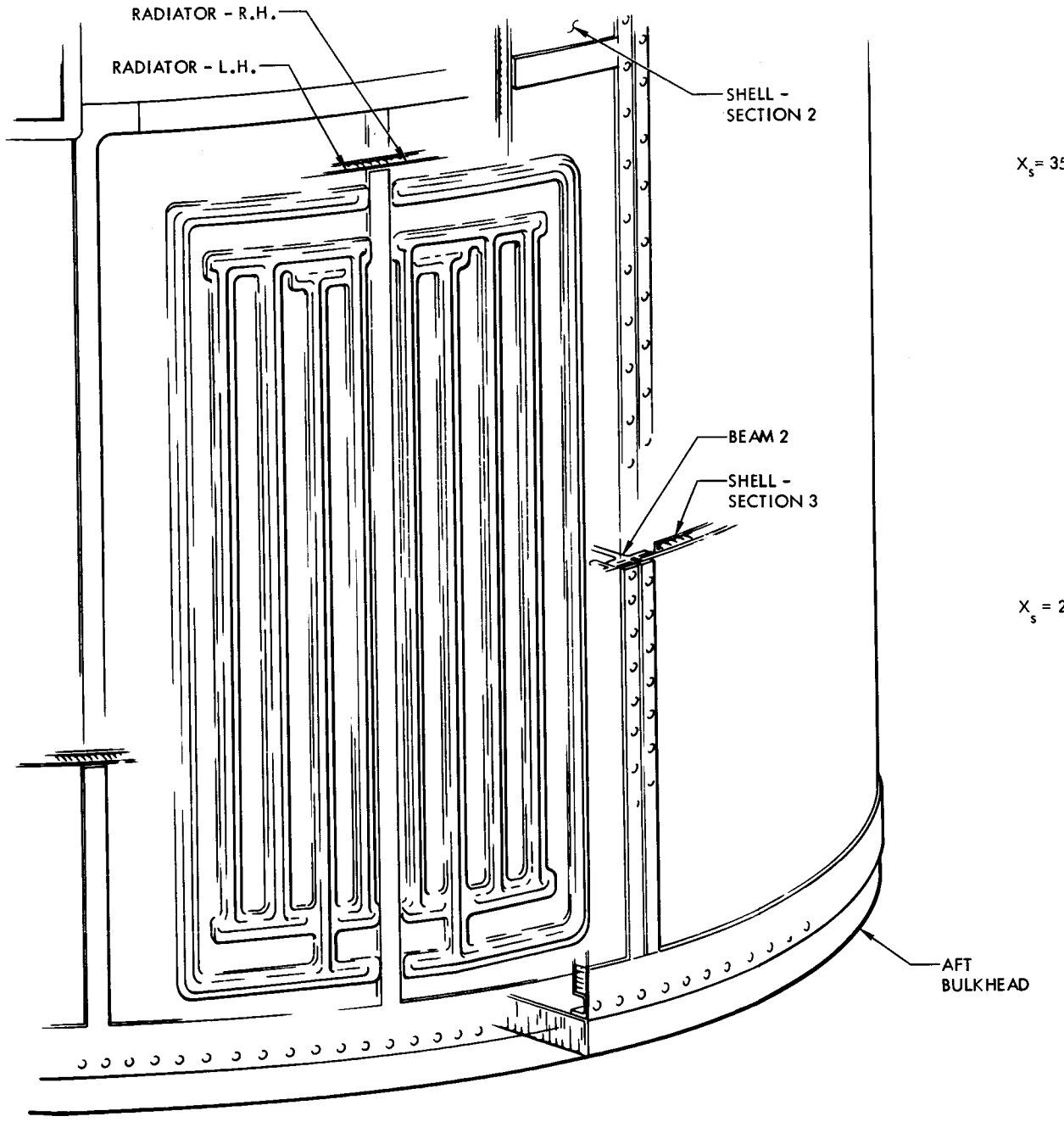
8. Determine edge effects of extended fin in space chamber.



TYPICAL SHELL PENETRATION



RADIATOR-SECTION 5 (HONEYCOMB PANEL NOT SHOWN)



RADIATOR-SECTION 2

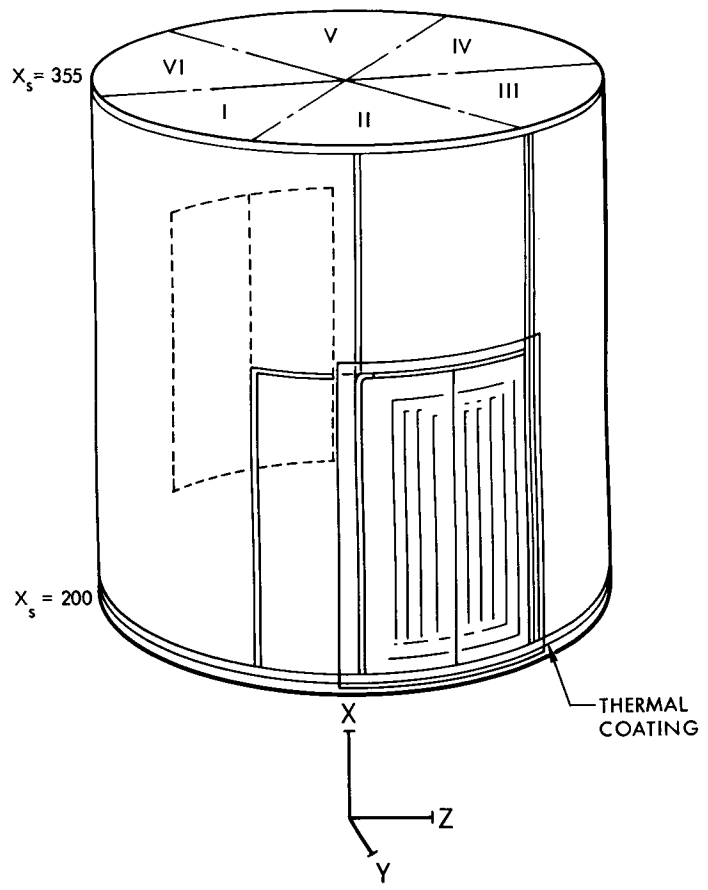


Figure 5-5. Radiators (60-sq ft) for Lunar Orbital Mission

[redacted]

9. Determine thermal effects of honeycomb backing.

10. Verify thermal coating requirements of solar absorptivity (α) of 0.15 and an infrared emissivity (ϵ) of 0.95.

11. Evaluate material and finishes compatibility.

12. Evaluate and demonstrate integrated system performance.

5.3.2.4 Tests

The following tests are required for the development and qualification program of the radiator panels.

5.3.2.4.1 Development Test. The development testing is divided into three areas:

1. Preliminary testing

2. Environmental testing

3. Performance testing

Development Tests will provide data from flow, temperature, thermal properties, space environment, and full-environment simulated operation of radiator panels for any re-design requirements needed.

5.3.2.4.1.1 Preliminary Tests:

1. Receiving and Inspection will check the radiator for conformance to design, specification, and fabrication requirements as per Drawings No. V17-615002, V17-616005, and SCD ME367-006.

2. Leakage Test - EDL will perform the following leakage test. Install radiator panel in a test fixture and apply an air pressure of 150 ± 5 psig and hold for one hour. Record any leakage or variations. A helium leak detector test or an ambient water immersion test may be used if approved by ECS.

3. Proof-Pressure Test - EDL will perform the proof-pressure testing. Install radiator panel in a test fixture and apply an internal hydrostatic proof-pressure of 150 ± 5 psig at ambient conditions and hold for one hour. Repeat leakage test after proof-pressure test.

[redacted]

[redacted]

5.3.2.4.1.2 Environmental Test. The following tests will be performed to determine the structural integrity of the radiator panels when subjected to the natural (climatic) and induced environmental conditons which the radiator panels must withstand. All panels of each test will be checked.

1. Shock Test - Place radiator panel with support on test fixture for impact shock along the major lateral axis in both directions and along the longitudinal axis (flight axis) in both directions. Fill radiator panels with ethylene-glycol water solution and pressurize to 150±5 psig. Subject panel to the following shock levels:

   25g for 11 ± 1 millisecond (triangular wave)

   25g for 8 ± 1 millisecond (sine wave)

   25g for 6 ± 1 millisecond (square wave)

   Above shocks are required in both directions along each of the major axes of the radiator panel.

   Perform leakage test specified in paragraph 5.3.2.4.1.1 upon completion of shock test.

2. Vibration Test - Place radiator panel with support on test fixture for vibration along each of the lateral axes and along the longitudinal axis. Fill the radiator panels with ethylene-glycol water solution and pressurize to 150±5 psig. Subject the panel to the following conditions along each axis:

   a. Scan the frequency range from 5 to 2000 (cps) in 30 minutes (twice in each of the three major axis, noting the frequency of all resonant points):

Frequency (cps)	Vibration
5-10	0.030 inch D. A.
10-20	±1.6 G
20-63	0.075 inch D. A.
63-2000	±15 G

b. The resonant frequency noted above will be applied for 5 minutes of vibration in each of the three major axes under 5-20 cps @ 1.6G and 20-63 cps @ 0.07 inch D. A.

c. Perform leakage test upon completion of vibration test.

3. Acceleration Test - Place the radiator panel on test fixture for acceleration application along the major lateral axis in both directions and for application of acceleration along the longitudinal axis (flight axis) in the flight direction. Fill radiator panel with ethylene-glycol water solution and pressurize to 150± 5 psig:

   a. Apply acceleration of 25g for 10±1 minutes along each axis.

   b. Perform leakage test upon completion of acceleration test.

4. Acoustical Vibration Test - Place radiator panel on test fixture to apply acoustical vibration. Fill radiator panel with ethylene-glycol water solution and pressurize to 150± 5 psig:

   a. Apply acoustical vibration to the radiator panel: 37.5 to 9600 cps @ 137 db.

   b. Perform leakage test upon completion of the acoustical vibration test.

5. Salt Spray Test - With a specified coating on the radiator panel, test per MIL-STD-810, Method 509.

6. Sunshine Test - With a specified coating on the radiator panel, test per MIL-STD-810, Method 505.

7. Humidity Test - With a specified coating on the radiator panel, test per MIL-STD-810, Method 507.

5.3.2.4.1.3 Performance Test. The following test will be performed in a space chamber to simulate the actual conditions under which the radiator will be required to operate. The simulation of thermal loads will be achieved by adjusting the ethylene-glycol inlet temperatures and flow rates. The simulation of environmental conditions will be achieved by the use of a cold wall, infrared heat source, solar simulator, and space chamber.

1. Simulate earth orbit with X-axis tangent to trajectory. Heat inputs will be simulated by means of an infrared heat source.

    a. Place the radiator in the vacuum chamber. Decrease the chamber pressure to 10^{-5} Torr while lowering the cold-wall temperature to -320 F. For thermocouple location, see Figures 5-6 and 5-7.

    b. Start ethylene-glycol water circulating pump and supply coolant to the radiator inlet at 97.3 F and 100 lb/hr. These values are to be held constant during this phase of testing. Allow sufficient time for all readings to remain constant.

    c. Supply heat to the radiator as indicated in Table 5-1. Heat is to be applied as shown in Figure 5-8. Change the environmental incident radiation at times indicated.

    d. All data, including magnitude of environmental incident radiation, cold-wall temperature, radiator temperatures, and pressure drops, will be continuously recorded as a function of time.

    e. With the same setup, repeat the procedure, but vary the environmental incident radiation as indicated in Table 5-2.

    f. Record all data as in (d).

2. Simulate translunar coast. This test will consist of three parts:

    a. A full radiator will be utilized with all circuits open. No solar radiation will be applied. (See Figure 5-9.)

        (1) Place the radiator in the vacuum chamber. Decrease the chamber pressure to 10^{-5} Torr while lowering the cold-wall temperature to -320 F. For test setup and thermocouple location see Figures 5-6 and 5-10.

        (2) Start water-glycol circulating pump and supply coolant to the panels at 200 lb/hr and an inlet temperature of 70 F.

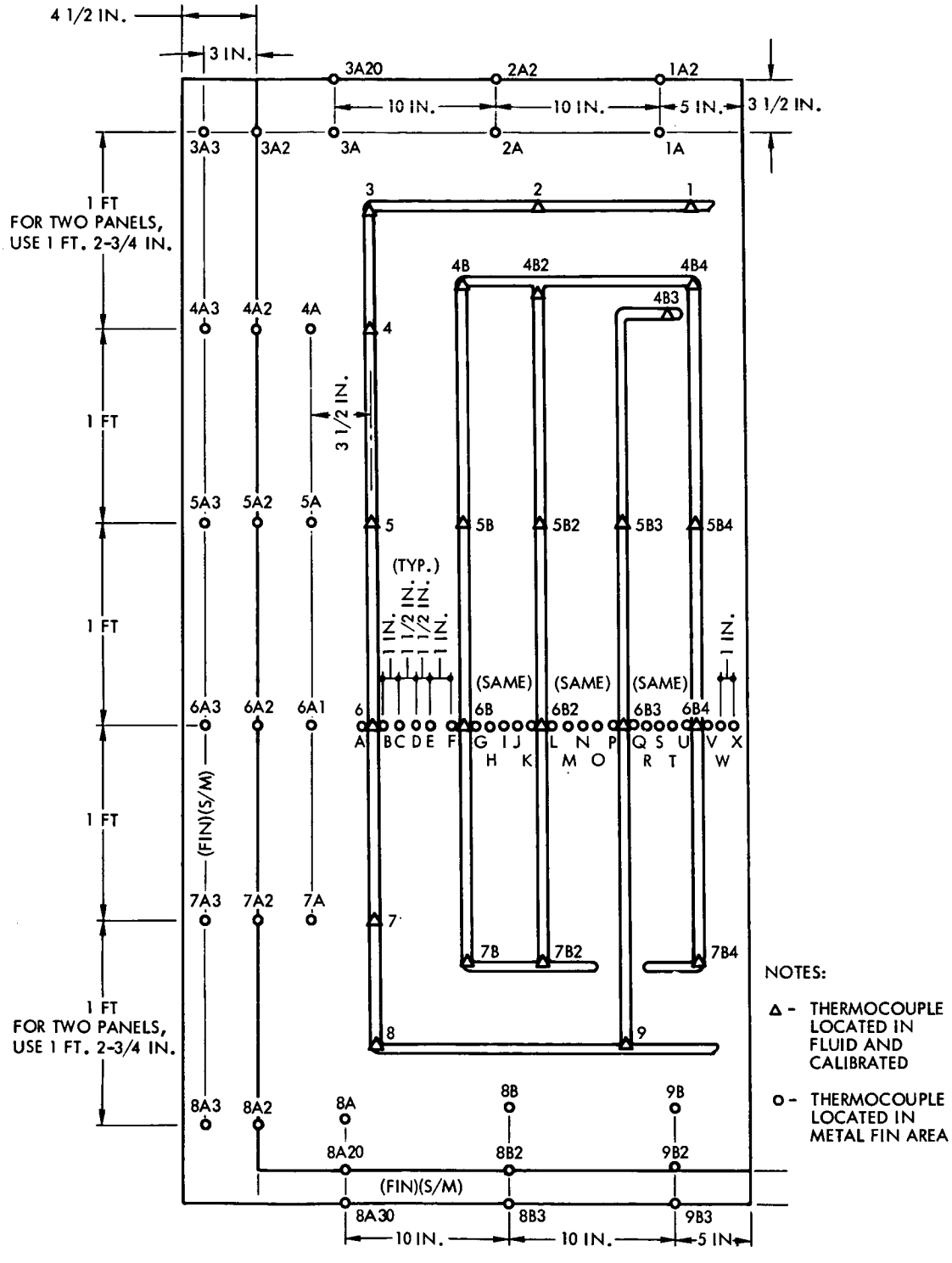


Figure 5-6. Thermocouple Location (ECS)

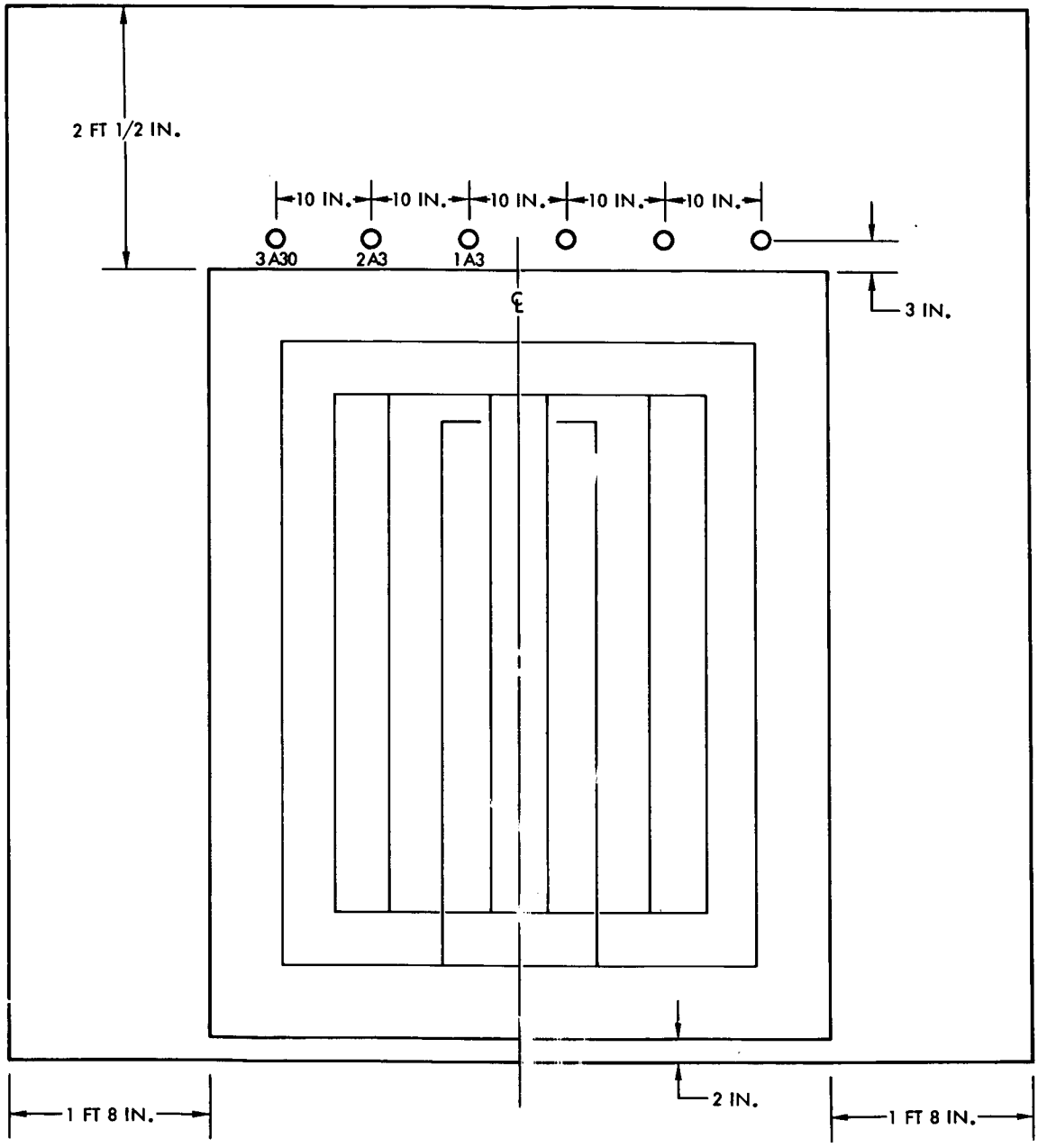


Figure 5-7. Thermocouple Edge Location on Service Module (ECS)

Table 5-1. Incident IR Radiation With X-Axis Parallel to Earth Surface

RADIATOR NO. 1				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-5	1	10	26
20	5-10	1	10	26
40	10-15	1	10	31
60	15-20	20	23	33
80	20-25	223	35	36
100	25-30	322	45	38
120	30-35	335	51	40
140	35-40	404	53	40
160	40-45	376	50	40
180	45-50	306	43	38
200	50-55	201	33	36
220	55-60	74	20	33
240	60-65	1	10	36
260	65-70	1	10	26
280	70-75	1	10	26
300	75-80	1	10	26
320	80-85	1	10	26
340	85-90	1	10	26

Note: When thermocouples 100 and 4B3 show no temperature difference, or when the temperature at 4B3 is greater than at 100, stop flow in the panel by closing the control valves and continue with test. When temperature at 4B3 becomes less than 100, reopen control valves and continue with test.

When thermocouple 200 reads less than -20 F, shut off primary circuit and continue with test. When temperature returns to above -20 F, reopen primary circuit and continue with test.

*Zero-time starts at midpoint of dark-side lunar orbit operation.

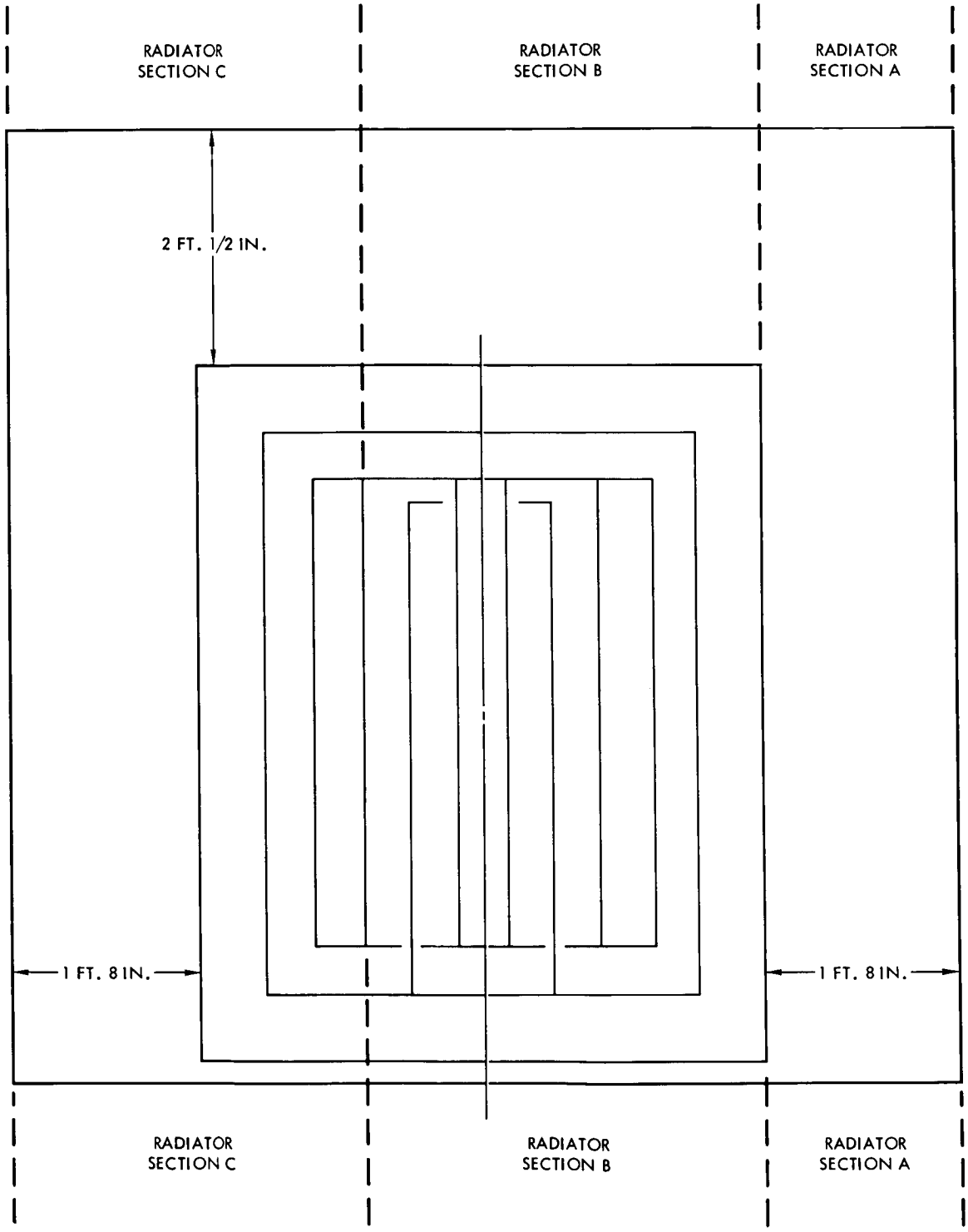


Figure 5-8. Heat Application Areas (ECS)

Table 5-2. Incident IR Radiation With X-Axis Parallel to Earth Surface

RADIATOR NO. 2				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-5	60	44	26
20	5-10	60	44	26
40	10-15	60	44	26
60	15-20	87	47	28
80	20-25	129	52	30
100	25-30	162	56	33
120	30-35	184	58	34
140	35-40	190	59	35
160	40-45	181	58	34
180	45-50	157	55	32
200	50-55	121	51	30
220	55-60	79	46	27
240	60-65	121	46	27
260	65-70	60	44	26
280	70-75	60	44	26
300	75-80	60	44	26
320	80-85	60	44	26
340	85-90	60	44	26

Note: When thermocouples 100 and 4B3 show no temperature difference or when the temperature at 4B3 is greater than at 100, stop flow in the panel by closing the control valves and continue with test. When temperature at 4B3 becomes less than at 100, reopen control valves and continue with test.

When thermocouple 200 reads less than -20 F, shut off primary circuit and continue with test. When temperature returns to above -20 F, reopen primary circuit and continue with test.

*Zero-time starts at midpoint of dark-side lunar orbit operation.

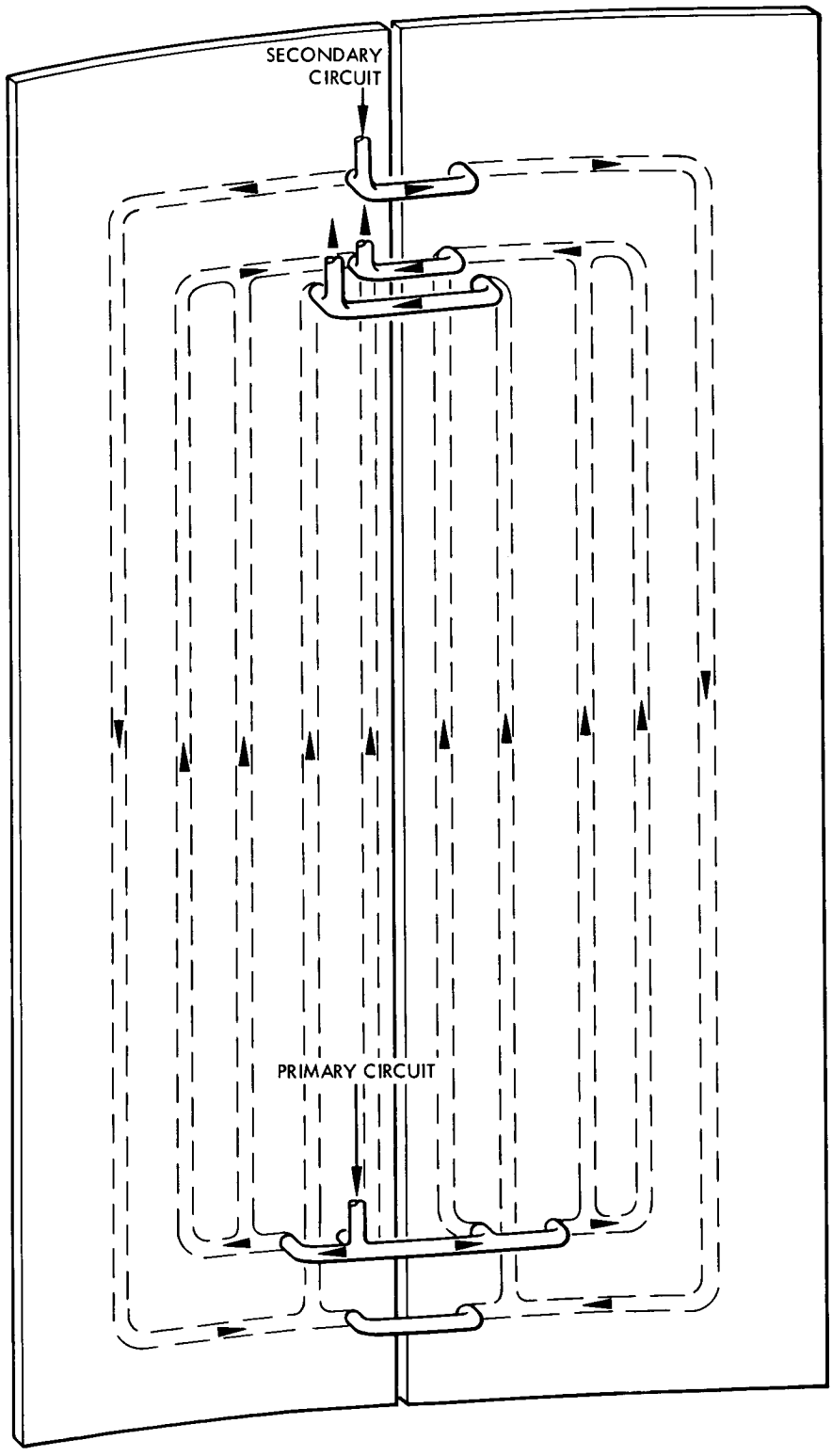


Figure 5-9. Fluid Flow Diagram: 60-sq ft Radiator (LOM)

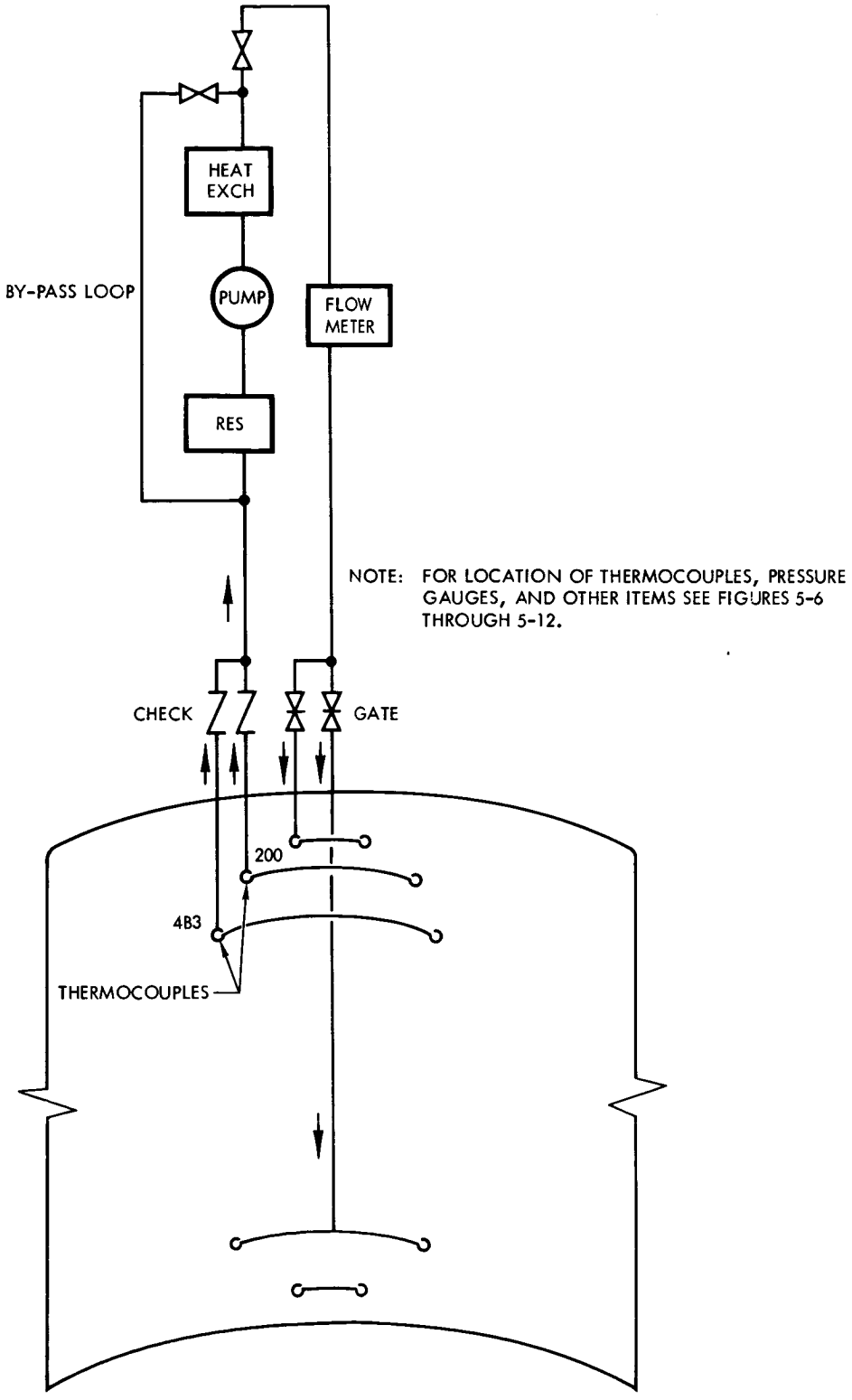


Figure 5-10. Test Setup

[redacted]

(3) Allow sufficient time for stabilization (record readings every 15 minutes), then record temperatures, flow rate, pressures, and ΔP across panels as indicated in paragraph 5.3.2.9.4.

(4) Measure liquid ΔT across the radiator and calculate the heat rejection rate. Measure radiator metal temperature and calculate the heat rejection rate.

(5) Using the chamber environment in (1), perform tasks in (4) for each condition listed in Table 5-3.

b. The same full radiator will be utilized with only the secondary circuits open. No solar radiation will be applied. For test setup and thermocouple location, see Figures 5-9 and 5-10.

(1) With the radiator in the vacuum chamber, decrease the chamber pressure to 10^{-5} Torr while lowering the cold-wall temperature to -320 F.

(2) Start water-glycol circulating pump and supply coolant to the panels at 50.0 lb/hr and under an inlet temperature of 81.8 F.

(3) Allow sufficient time for stabilization (record readings every 15 minutes), then record temperatures, flow rate, pressure, and ΔP across the panels as indicated in paragraph 5.3.2.9.4.

(4) Measure liquid ΔT across the radiator and calculate the heat rejection rate. Measure radiator metal temperature and calculate the heat rejection rate.

(5) Using the chamber environment in (1), perform tasks in (3) and (4) for each of the conditions listed in Table 5-4.

[redacted]

Table 5-3. Test Conditions for Simulated Translunar Coast

Run No.	Coolant Flow Rate (Lb/Hr/ Radiator)	Coolant Inlet Temperature (°F)	Simulated Environmental Conditions		
			Cold Wall (°F)	Solar Simulator (Btu/Hr/Ft^2)	Infrared Source (Btu/Hr/Ft^2)
1	*20.0	70.0	-320	0.0	0.0
2	*40.0	74.5	-320	0.0	0.0
3	50.0	74.5	-320	0.0	0.0
4	80.0	74.5	-320	0.0	0.0
5	100.0	74.5	-320	0.0	0.0
6	100.0	81.8	-320	0.0	0.0
7	80.0	81.8	-320	0.0	0.0
8	50.0	81.8	-320	0.0	0.0
9	40.0	81.8	-320	0.0	0.0

*Coolant may "freeze" in duct, i.e., pressure drop across duct may exceed 10 psia. If this happens, record all data and proceed to next run.

[redacted]

Table 5-4. Test Conditions for Simulated (Secondary Circuit Operation) Translunar Coast

Run No.	Coolant Flow Rate (Lb/Hr)	Coolant Inlet Temperature (°F)	Simulated Environmental Conditions		
			Cold Wall (°F)	Solar Simulator ($Btu/Hr/Ft^2$ Irrad)	Infrared Source ($Btu/Hr/Ft^2$ Irrad)
10	18.0	81.8	-320	0.0	0.0
11	25.0	81.8	-320	0.0	0.0
12	50.0	81.8	-320	0.0	0.0
13	50.0	74.5	-320	0.0	0.0
14	25.0	74.5	-320	0.0	0.0
15	18.0	74.5	-320	0.0	0.0
16	10.0	70.0	-320	0.0	0.0
17	6.0	70.0	-320	0.0	0.0

[redacted]

c. An abbreviated radiator, facing directly toward a solar simulator, will be used for this part. For test setup and thermocouple location, see Figures 5-10 and 5-11.

(1) With the radiator in the vacuum chamber, decrease the chamber pressure to 10^{-5} Torr while lowering the cold-wall temperature to -320 F.

(2) Start water-glycol circulating pump and supply coolant to the panel at 60 lb/hr and under an inlet temperature of 81.6 F.

(3) Allow sufficient time for stabilization, then record all temperatures, flow rate, pressures, and ΔP across the panels as in paragraph 5.3.2.9.4.

(4) Using the chamber environment in (1), subject radiator to conditions listed in Table 5-5 and record all data.

3. Simulate lunar orbit. This test will consist of two radiator orientations. (See Figure 5-12 for radiator orientation and numbering.) Heat input will be provided by an infrared heat source.

This portion of testing might be coordinated with the earth-orbit portion to eliminate additional setups.

a. Orientation 1 — The X-axis of radiator number 2 is perpendicular to the lunar surface.

(1) Place the radiator in the vacuum chamber. Decrease the chamber pressure to 10^{-5} Torr while lowering the cold-wall temperature to -320 F. For thermocouple location, see Figures 5-6 and 5-7.

(2) Start ethylene-glycol water circulating pump and supply coolant to the radiator inlet at 200 lb/hr and under an inlet temperature of 81.8 F. These values are to be held constant during this phase. Allow sufficient time for all readings to remain constant.

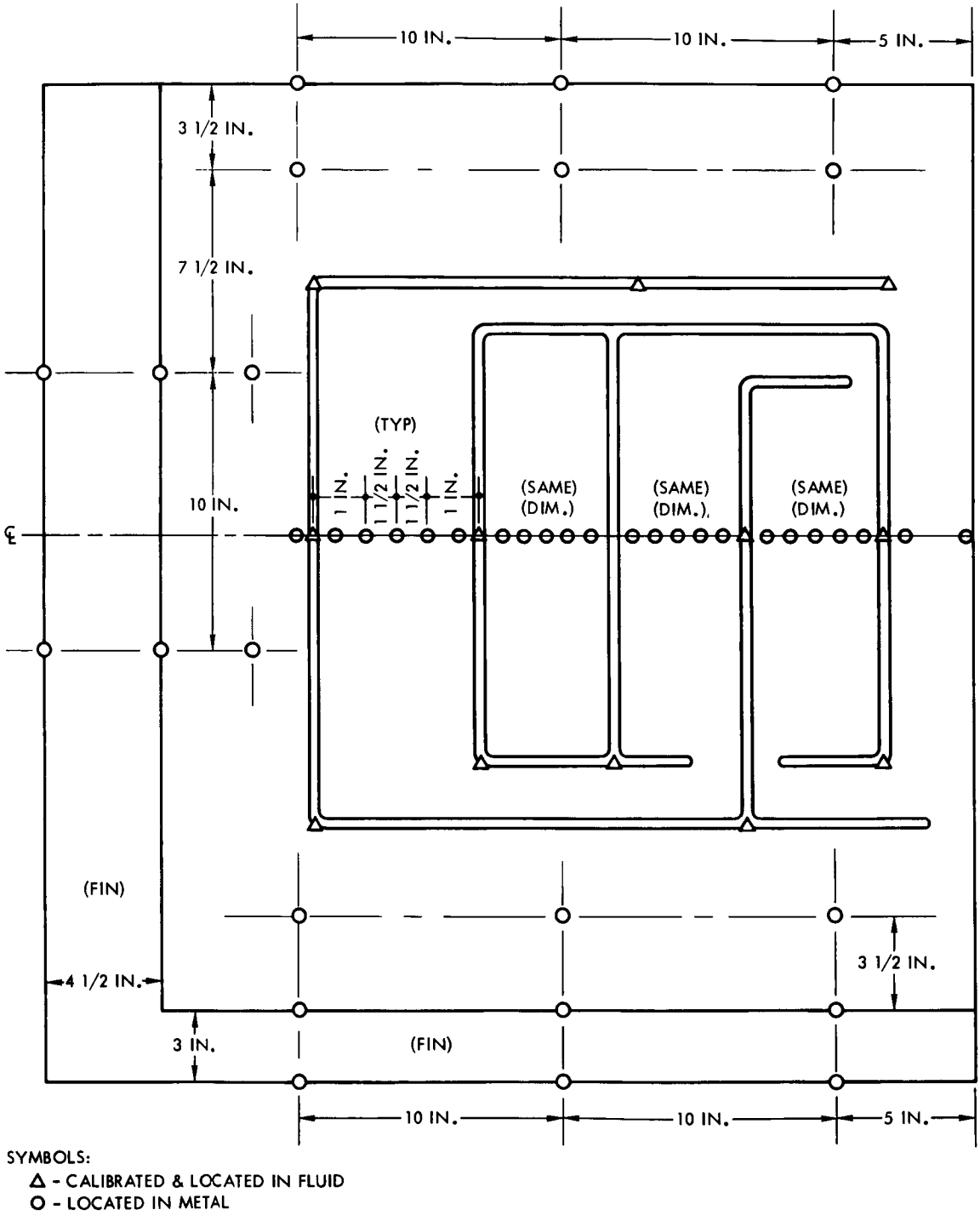


Figure 5-11. Solar Simulator Test Thermocouple Location

Table 5-5. Test Conditions for Simulated Operation of Panel Facing Sun

Run No.	Coolant Inlet Temperature (°F)	Angle of Panel (Degrees)	Coolant Flow Rate (Lb/Hr)	Simulated Environmental Conditions		
				Cold Wall (°F)	Solar Simulator Output (Btu/Hr/Ft^2) (2 Suns)	Infrared Source Output (Btu/Hr/Ft^2)
18	74.5	-90	120	-320	886	0
19	74.5	-90	120	-320	886	0
20	74.5	-30	120	-320	886	0
21	74.5	0	120	-320	886	0
22	74.5	±30	120	-320	886	0
23	74.5	+60	120	-320	886	0
24	74.5	+90	120	-320	886	0
25	81.6	+90	120	-320	886	0
26	81.6	+60	120	-320	886	0
27	81.6	+30	120	-320	886	0
28	81.6	0	120	-320	886	0
29	81.6	-30	120	-320	886	0
30	81.6	-60	120	-320	886	0
31	81.6	-90	120	-320	886	0

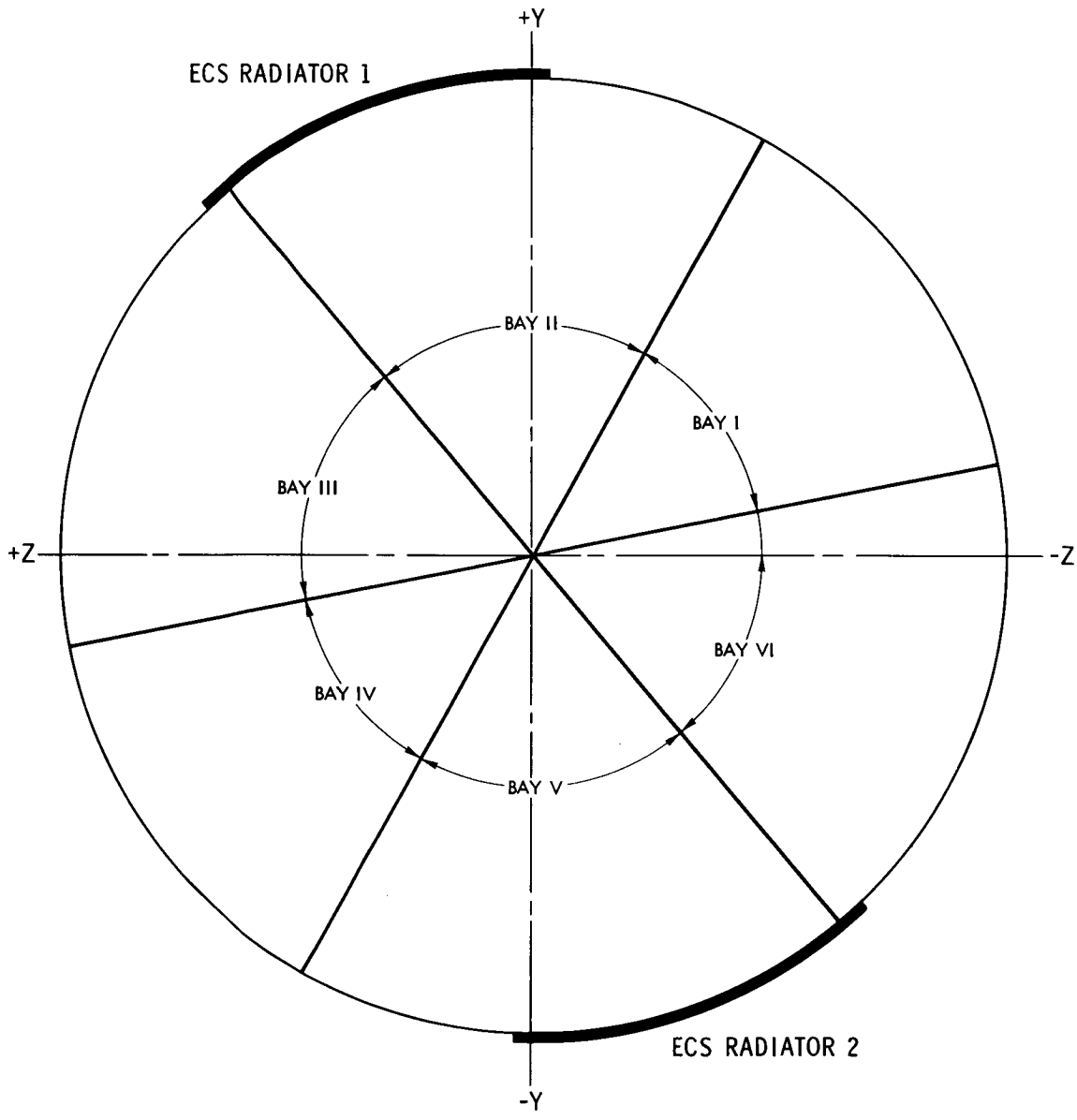


Figure 5-12. ECS Radiator Location

(3) Supply heat to the radiator as indicated in Table 5-6. Heat is to be applied as shown in Figure 5-8. Change the environmental incident radiation at times indicated regardless of the flow rate through the panel. Refer to note on Table 5-6.

(4) All data, including magnitude of environmental incident radiation, cold-wall temperature, radiator temperature, and pressure drops, will be continuously recorded as a function of time. Record the time at which any temperature, flow rate, or circuit switch has been changed from the normal operational mode. When any circuit has been switched off, do not vent it.

b. Orientation 1 (Deviated) — With the X-axis of radiator number 2 parallel to the lunar surface, repeat conditions in (a.1) through (a.4), but use Table 5-7 for environmental incident radiation application.

(Note: Under actual system operation, the full radiator system flow rate of 200 lb/hr is diverted into one radiator when the other radiator is switched off. Thus, in this run it will be necessary to flow 200 lb/hr at the time in orbit that radiator number 2 is completely switched off.)

c. Orientation 2 — With the X-axis of radiator number 1 perpendicular to the lunar surface, proceed as in (a.1) through (a.4), but use Table 5-8 for environmental incident radiation. (See note above.)

d. Orientation 2 (Deviated) — With the X-axis of radiator number 1 parallel to the lunar surface, repeat conditions in (a.1) through (a.4), but use Table 5-9 for environmental incident radiation application.

5.3.2.4.1.4 Radiator Temperature Control Coatings Tests. Candidate coatings will be selected that exhibit promising optical and temperature control properties when evaluated against the major components of the space environment. Identical specimens coated with the selected materials will be subjected to the following screening tests.

1. Determine the emissivity and solar absorptivity of each candidate material using a total normal thermal emittance apparatus.

Table 5-6. Incident IR Radiation With X-Axis Perpendicular to Lunar Surface

RADIATOR NO. 2				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-7	1	1	1
20	7-14	1	1	1
40	14-21	1	1	1
60	21-28	1	1	1
80	28-35	1	36	1
100	35-42	22	54	20
120	42-49	60	84	54
140	49-56	91	105	82
160	56-63	111	112	100
180	63-70	118	107	107
200	70-77	242	101	101
220	77-84	337	82	82
240	84-91	392	54	54
260	91-98	399	20	20
280	98-105	379	1	1
300	105-112	1	1	1
320	112-119	1	1	1
340	119-126	1	1	1

Note: When thermocouples 100 and 4B3 show no temperature difference, or when the temperature at 4B3 is greater than at 100, stop flow in the panel by closing the control valves and continue with test. When temperature at 4B3 becomes less than at 100, reopen valves and continue with test.

When thermocouple 200 reads less than -20 F, shut off primary circuit and continue with test. When temperature returns to above -20 F, reopen primary circuit and continue with test.

*Zero-time starts at midpoint of dark-side lunar orbit operation.

[redacted]ENTIAL

Table 5-7. Incident IR Radiation X-Axis Parallel to Lunar Surface

RADIATOR NO. 2				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-7	4	2	1
20	7-14	4	2	1
40	14-21	4	2	1
60	21-28	4	2	1
80	28-35	70	8	1
100	35-42	64	39	20
120	42-49	178	108	54
140	49-56	271	165	82
160	56-63	353	201	101
180	63-70	353	214	107
200	70-77	332	201	101
220	77-84	271	165	82
240	84-91	178	108	54
260	91-98	64	39	20
280	98-105	70	8	1
300	105-112	4	2	1
320	112-119	4	2	1
340	119-126	4	2	1

Note: When thermocouples 100 and 4B3 show no temperature difference, or when the temperature at 4B3 is greater than at 100, stop flow in the panel by closing the control valves and continue with test. When temperature at 4B3 becomes less than at 100, reopen control valves and continue with test.

When thermocouple 200 reads less than -20 F, shut off primary circuit and continue with test. When temperature returns to above -20 F, reopen primary circuit and continue with test.

*Zero-time starts at midpoint of dark-side lunar orbit operation.

[redacted]

[redacted]

Table 5-8. Incident IR Radiation X-Axis Perpendicular to Lunar Surface

RADIATOR NO. 1				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-7	1	1	1
20	7-14	1	1	1
40	14-21	1	1	1
60	21-28	1	1	1
80	28-35	379	1	1
100	35-42	399	20	20
120	42-49	392	54	54
140	49-56	337	82	82
160	56-63	242	101	101
180	63-70	118	107	107
200	70-77	111	112	101
220	77-84	91	105	82
240	84-91	60	84	54
260	91-98	22	54	20
280	98-105	1	36	1
300	105-112	1	1	1
320	112-119	1	1	1
340	119-126	1	1	1

Note: When thermocouples 100 and 4B3 show no temperature difference, or when the temperature at 4B3 is greater than at 100, stop flow in the panel by closing the control valves and continue with test. When temperature at 4B3 becomes less than at 100, reopen control valves and continue with test.

When thermocouple 200 reads less than -20 F, shut off primary circuit and continue with test. When temperature returns to above -20 F, reopen primary circuit and continue with test.

*Zero-time starts at midpoint of dark-side lunar orbit operation.

[redacted]

Table 5-9. Incident IR Radiation X-Axis Parallel to Lunar Surface

RADIATOR NO. 1				
Orbit Time (Degrees)	Test Time (Minutes)	IR Radiation (Btu/Hr/Ft^2)		
		Section A	Section B	Section C
*0	0-7	0	0.3	1
20	7-14	0	0.3	1
40	14-21	0	0.3	1
60	21-28	0	0.3	1
80	28-35	0	0.3	1
100	35-42	67	11	20
120	42-49	192	32	54
140	49-56	294	49	82
160	56-63	360	60	101
180	63-70	384	64	107
200	70-77	360	60	101
220	77-84	294	49	82
240	84-91	192	32	54
260	91-98	97	11	20
280	98-105	0	0.3	1
300	105-112	0	0.3	1
320	112-119	0	0.3	1
340	119-126	0	0.3	1

*Zero-time starts at midpoint of dark-side lunar orbit operation.

[redacted]

Two panels, 2 in. x 2 in. x 0.32 in., of each material shall be tested. Properties shall be determined at 500 F, 225 F, and one lower temperature, if possible, while at atmospheric pressure.

2. Expose two panels, 7/8-in. diameter x 0.032 in., of each coating to a vacuum of from 10^{-7} to 10^{-10} mm Hg, for a minimum of 48 hours. Weight loss due to sublimation, outgassing, or other degradation shall be measured.

3. Expose two panels, 7/8-in. diameter x 0.32 in., of each coating to ultraviolet radiation (one solar) for a minimum of 48 hours at atmospheric pressures. Any appreciable color changes shall be cause for rejection.

After screening each coating against the major individual components of the space environment, each set of coated specimens will be tested under the following major environments, consecutively. A minimum of two test specimens of each coating, 7/8-in. diameter x 0.032 in., will be used. Only materials that have passed the screening tests will be evaluated.

1. Each specimen will be submitted to a postlaunch environmental test to determine the effect of heat and vacuum on coatings that will be encountered during the ascent phase, just after launching. The coatings will be exposed to approximately 600 F for 30 to 60 seconds at a constant pressure of 10 mm Hg. The test will be repeated at a constant pressure of 10^{-3} mm Hg. Total normal emittance will be determined before and after this test. These properties will be determined at 225 F. Coatings that prove unsatisfactory will not be further tested.

2. Each specimen will be exposed to a vacuum of 10^{-8} mm Hg minimum for 500 hours. Loss of weight and the radiative properties of each coating will be determined before and after the test.

3. Each specimen will be exposed to ultraviolet radiation (one solar) for 500 hours. Visual examination and radiative properties will be determined before and after the test.

[redacted]

4. Each specimen will be exposed to a combination of high vacuum (10^{-8} mm Hg) ultraviolet radiation (one sun) for 500 hours. Radiative properties will be determined before and after each test.

5. Each specimen will be subjected to a single exposure of one hour to a temperature of -420 ± 10 F. Each coating will be examined for deleterious effects, and the radiative properties will be determined before and after the exposure.

6. Each specimen will be exposed to micrometeroid impact. The specimens will be so tested as to avoid any edge effect. Each specimen will be examined to determine the degree of degradation. If the coating remains intact, the radiative properties will be determined.

7. Methods of handling and protecting radiators that have temperature coatings will be developed. A protective covering will be developed that will shield the coating from contamination during storage.

8. Deterioration of the radiative properties of a coating after storage will be determined.

9. Coatings that prove unsatisfactory during the above tests will be reformulated, if possible, to improve their performance. Coatings that cannot be improved to meet these tests will be rejected.

Coatings that appear promising after the various tests listed above have been completed will be tested as follows:

1. Two test specimens, 1-in. diameter discs, will be coated with candidate coatings and their radiative properties determined. The two specimens will then be subjected to the tests of (2) through (6) above simultaneously. Optical properties will be determined and recorded after each test.

2. Model radiators will be fabricated and tested under simulated space environments and at operational heat rejection loads. These radiators will use the coatings that prove the most satisfactory above. The results of these tests will determine the final material.

Supplementary Information.

1. Reaction control system space exhaust plume tests. Combustion products from the RCS and sublimation products from the RCS nozzle may deposit on or near the space radiator surfaces during flight. Tests to predict the amount of radiator surface

[redacted]

contamination possible, and the effect of this contamination on the radiator surface coating optical and mechanical properties, will be run in conjunction with the hot firing tests of the full scale RCS motors under near-vacuum conditions.

2. Actual space environment tests. When possible, candidate coatings will be subjected to actual space environments by placing them onboard orbiting vehicles. The frequency with which these tests are conducted will depend on the limitation existing for instrumentation space on the vehicle and test priorities. These tests will be coordinated through NASA.

3. Space vehicle contaminants test. A series of tests will investigate the effects of common space vehicle contaminants (propellant, lubricants, etc.) on the optical and mechanical properties of the candidate coatings. The necessary precautions and techniques for providing protection for the radiator surface will be developed in a parallel effort.

4. Nuclear radiation. Each coating will be exposed to nuclear radiation conforming to the NASA-supplied profile for the mission. The coatings will be examined to determine any degradation, and the radiative properties will be remeasured to determine any change in optical properties.

5.3.2.4.2 Qualification Test. The qualification testing will consist of selected testing from the development testing plan plus special testing for reliability evaluation.

The qualification test program for the prototype radiator panels will repeat much of the test procedure for the development radiator panels.

5.3.2.5 Order of Tests

For both the development and qualification programs, tests that will cause little or no damage to the radiator panels will be scheduled first.

5.3.2.6 Test Records

Radiator panels are to be assigned numbers. As the radiators are processed and tested, all data pertaining to that panel will be referenced with the number assigned. Copies of all data will be forwarded to ECS.

5.3.2.7 Failures

In the event of a malfunction, the test will be stopped, and an inspection of the test setup will be started to determine the cause. Prior to resuming testing, ECS will be notified and all data pertinent to the malfunction will be recorded. If the cause is not in the radiator panels, the malfunction can be repaired and testing resumed.

5.3.2.8 Cleanliness

All surfaces of the radiator panel will be kept clean, free of any foreign matter.

5.3.2.9 Equipment Requirements

The items listed and described below represent the major components needed for the development and qualification testing of the radiator panels. Any deviations, additions, or deletions by the testing group must have ECS approval prior to start of test.

5.3.2.9.1 Radiator Panels. Eight panels will be provided to begin the development testing. Present plans require various tests to be run simultaneously on different radiator panels at EDL or wherever test facilities are available.

The radiators will be fabricated to the design specifications described on drawings No. V17-615002 and V17-616005.

Radiator panels specified by ECS will have spacecraft aluminum foil bonded to the back by the testing group to simulate configuration requirements. Not all panels will have spacecraft covering on the back. (See drawing V17-322030 for sketch of aluminum foil backing.)

5.3.2.9.2 Solar Simulator. The solar simulator will be capable of producing an irradiation up to one sun normal to the entire test specimen surface and of varying the source strength or the view factor to the radiator surface as a function of time without significant change in the wave lengths of the radiation. It will also provide the following:

1. Incident Solar Radiation - The incident energy will be composed of the following spectral percentages and will correspond to the solar spectral distribution:

Ultraviolet	(2000 - 3800 A°)	8%±1%
Visible	(3800 - 7000 A°)	41%±3%
Infrared	(7000 - 10,000 A°)	22%±3%
For Infrared	(10,000 - 20,000 A°)	23%±2%

All incident radiation is to be collimated or otherwise controlled to insure parallelism of the radiation within ±1.5 percent.

2. Reflected Solar Radiation From Earth - The reflected solar radiation from the earth will be composed of the following percentages of the incident radiation:

Ultraviolet — 50 percent
Visible — 40 percent
Infrared (all wave lengths) — 30 percent

The intensity of reflected solar radiation from the earth will be 159 Btu/hr/ft^2 ±5 percent.

3. Earth Emission - The heat flux of earth emission shall be 71 Btu/hr/ft^2 ±5 percent in the infrared region.

Radiator panels will experience no significant degradation in performance resulting directly or indirectly from exposure to solar radiation; if degradation occurs, test shall be classified "Failure" and reported to ECS for action.

(Ref. Figure 5-13, Solar Simulator Test—when large chamber is available.)

5.3.2.9.3 Infrared Heat Source. The infrared heat source will be capable of producing an irradiation up to 425 Btu/hr/ft^2 specimen and of varying the source strength or the view factor to the radiator surface with minimum changes in wave length of radiation as a function of time.

5.3.2.9.4 Instrumentation and Measuring Equipment. The following instruments are required for the test program. Additional instruments may be required by ECS at a later date. All instruments and recording devices will have an accuracy of within ±1 F.

1. Thermocouples (small gauge, insulated, precision-type) with a temperature range of 100 F to -60 F will be attached to the back of the radiator test panels. (See Figures 5-6, 5-7, 5-14, and 5-15. For location of thermocouples in solar simulation test, see Figure 5-11.)

Thermocouple readings will be recorded by an automatic recording device.

Thermocouples located at the inlet and outlet of water-glycol system will measure the temperature of the fluid and not the temperature of the surface of the coupling.

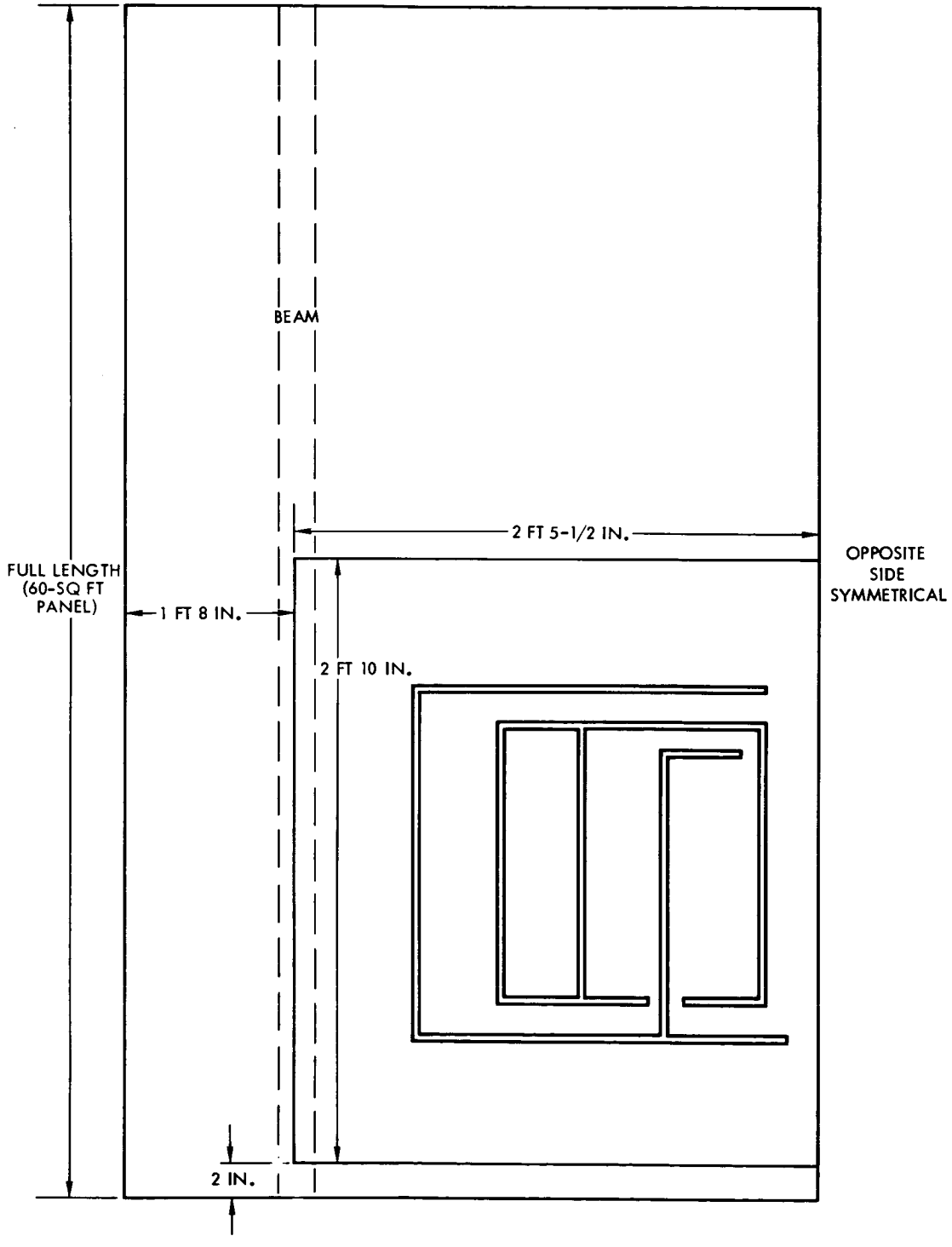


Figure 5-13. Solar Simulator Test (ECS)

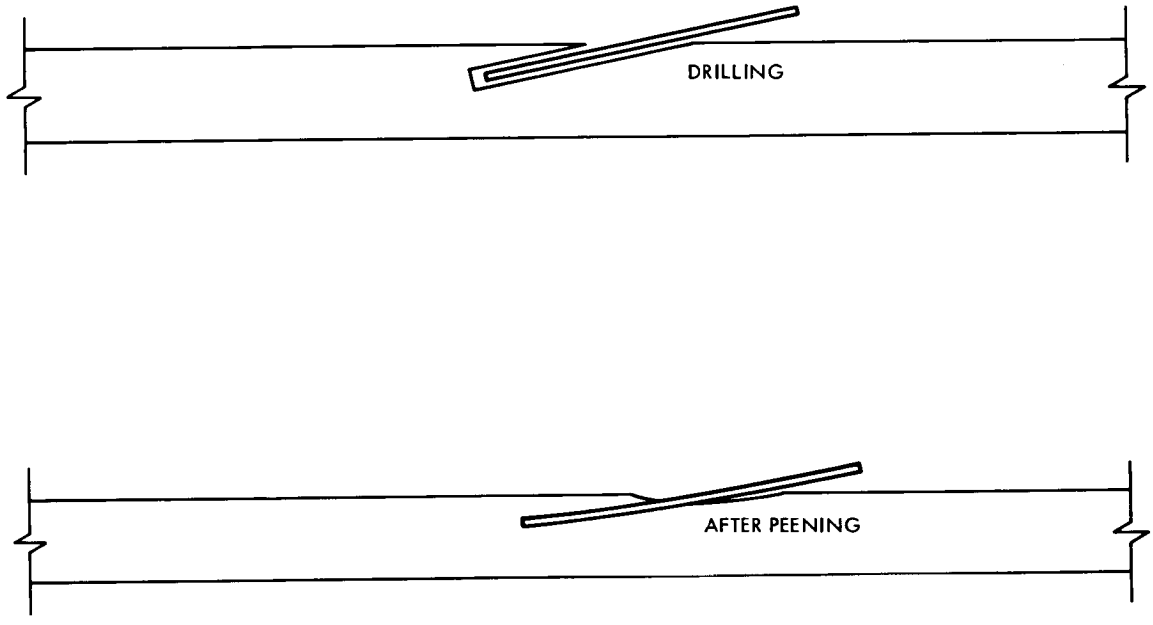


Figure 5-14. Thermocouple Attachment

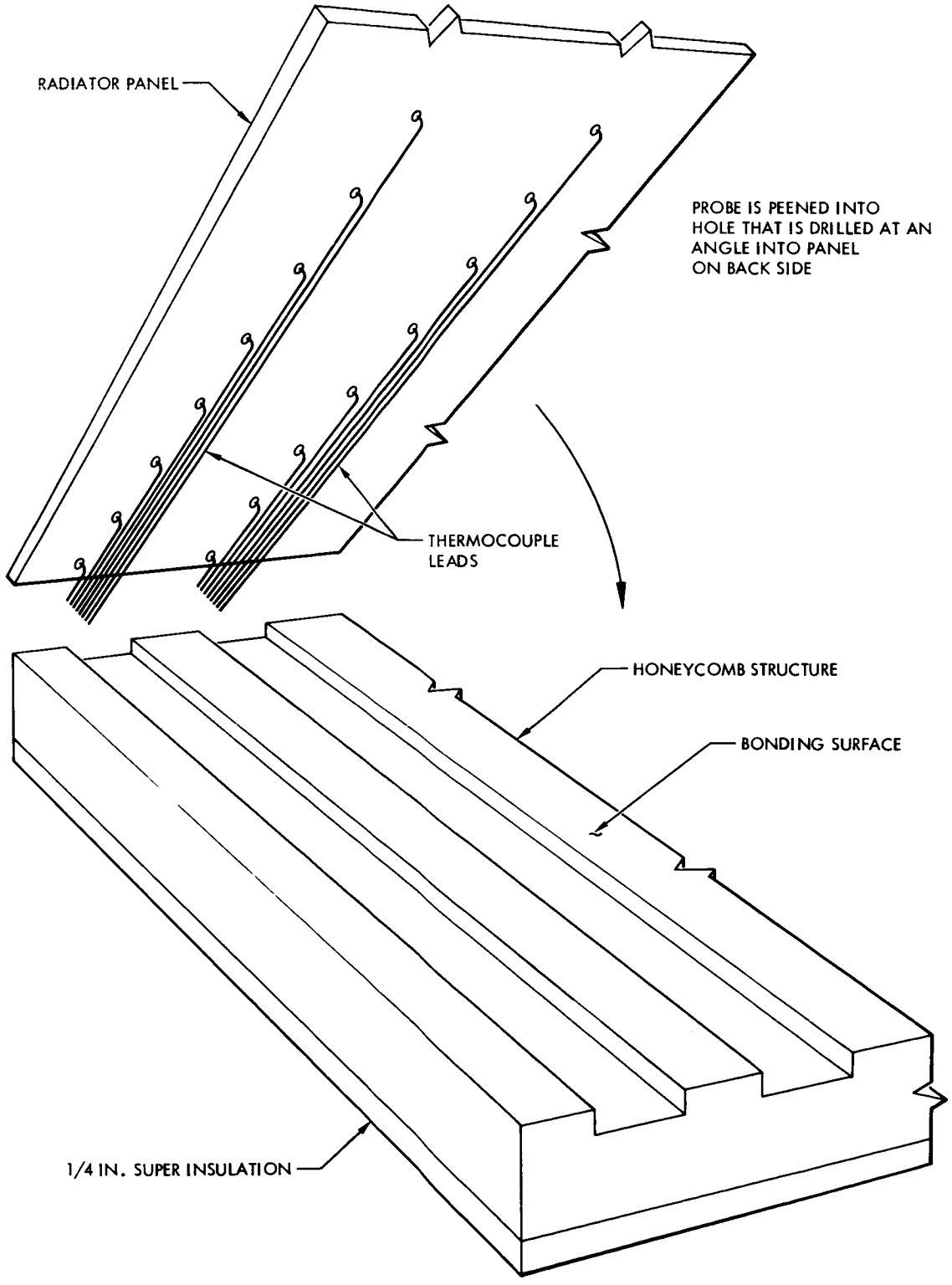


Figure 5-15. Method of Thermocouple Attachment (ECS)

Specified thermocouples will use exit temperature of primary circuit as reference to provide greater accuracy.

Specified thermocouples will be calibrated; at finish of test they will be recalibrated.

2. Differential pressure gauges will be used for readings across the radiator panels at various points as specified. (See Figure 5-10 for test setup.) Gauges will be capable of measuring pressure differentials within 0.1 psi at a maximum total pressure differential of 15 psi. (See Figure 5-16.)

3. A calibrated flowmeter will be required. Also, a backup of measuring and timing will be accomplished by catching the return liquid for a specified time. (See Figure 5-17.)

4. Portable optical measuring device—a Beckman DK-2 spectrophotometer or its equivalent.

5.3.2.10 Data Requirements

All data listed below will be recorded and the information transmitted for study by groups concerned. Any additional information not specified but which becomes available to the testing group also will be recorded.

1. Temperatures from all specified instrumented points will be continuously recorded during all phases of testing.

2. Inlet and ΔP pressures across panels are to be automatically and continuously recorded during all of the testing phases.

3. Flow rates of water-glycol are to be recorded automatically and continuously during all phases of testing.

4. Space-chamber cold-wall temperatures will be recorded automatically and continuously for various points that face the radiator panels. The emissivity of the cold wall will be recorded.

5.3.2.11 Facility Requirements

1. A space simulation chamber of sufficient capacity to hold the radiator panels. Maximum chamber pressure will be 1×10^{-5} Torr, and the chamber will have liquid nitrogen cooled walls that have been thermal coated to simulate a black body with an emissivity of 0.96. The cold wall will be maintained at -320 F for the duration of the test.

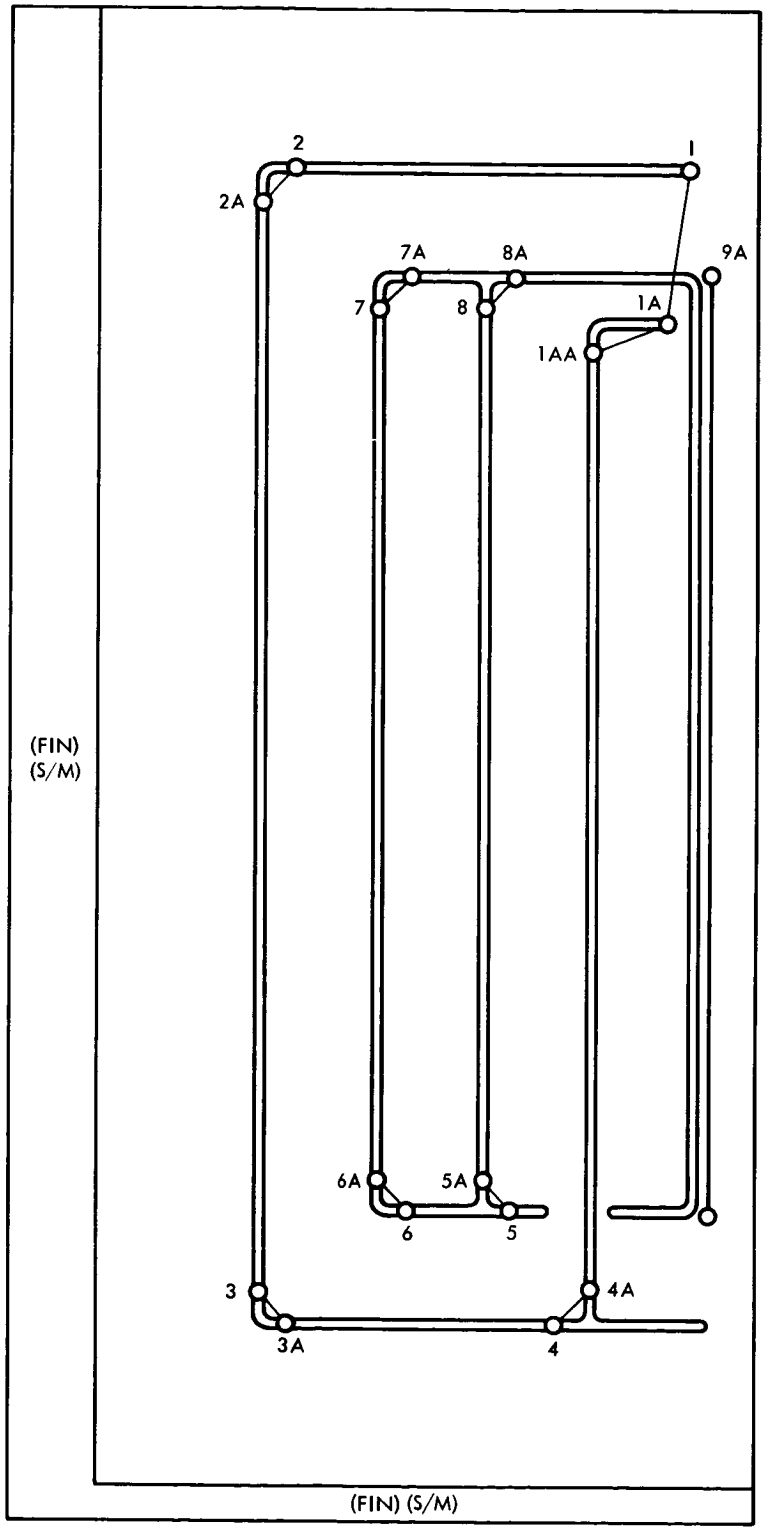


Figure 5-16. ECS Differential Pressure Gauge Location

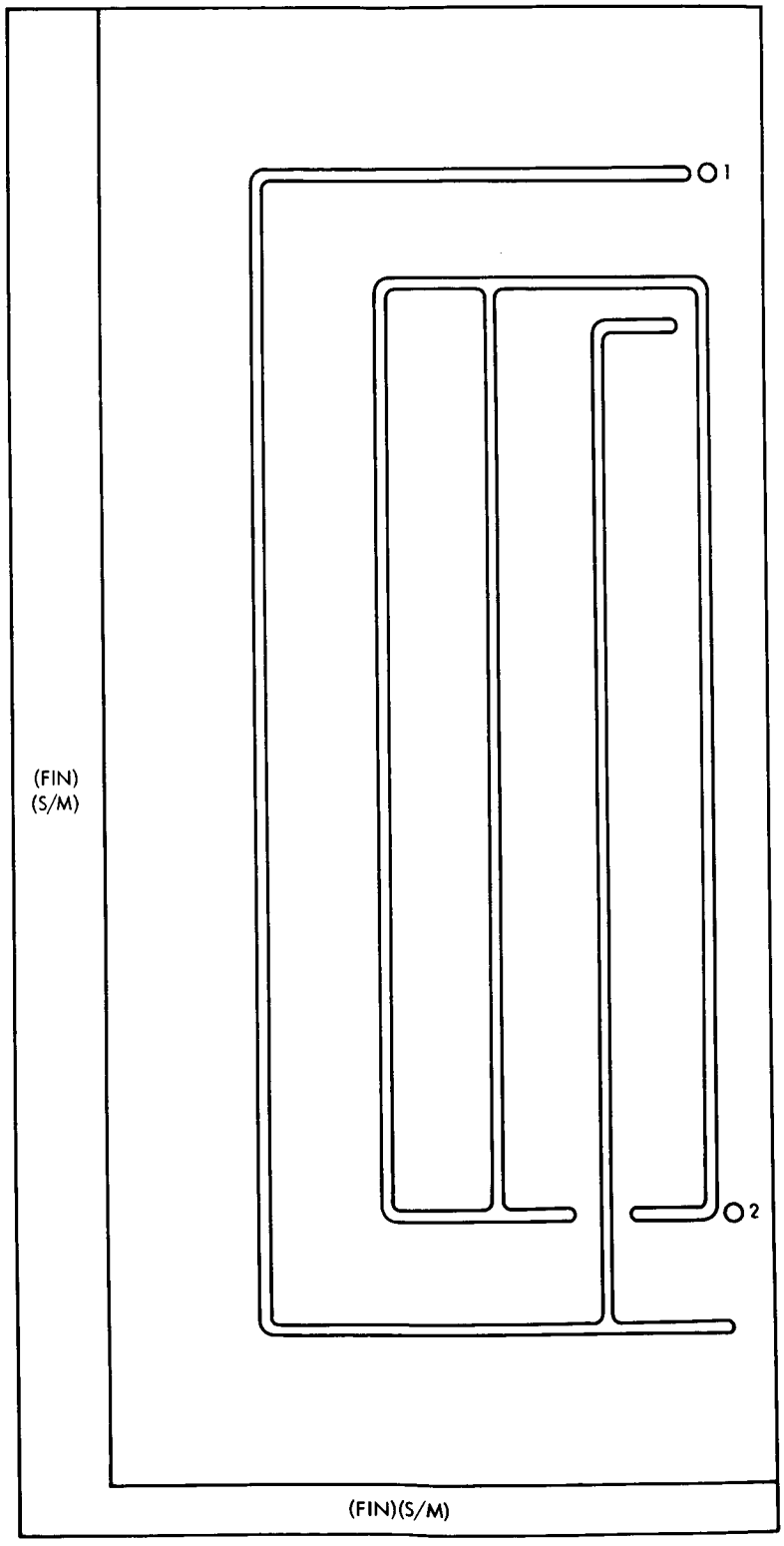


Figure 5-17. Flow Meter Locations (ECS Radiator Panel)

2. A circulating system (ethylene-glycol-water) including pump, heat exchangers, flow measuring device, flow control valves, pressure gauges, and differential pressure gauges. Mixture to consist of 62.5 percent ethylene-glycol and 37.5 percent distilled water. No cuprous material that would come in contact with the solution will be used in the test setup.

In addition, the system will provide constant flow rate up to 200 lb/hr, constant coolant inlet temperature in the range of 100 F to 70 F, and duct by-passing. The pump will be capable of operating against pressure head of 15 psi.

5.3.3 Coldplate Test

5.3.3.1 Test Objectives

The objectives are to evaluate and demonstrate the capability of an integrated network of coldplates to provide thermal control of the electronic equipment in the C/M under simulated mission environments and to verify that the water-glycol mixture is compatible with the material forming the network fluid passageways. The network will consist of a complete C/M coldplate system which will be verified structurally and functionally through AFRM 6 and 8, respectively. (Figure 5-18 shows the actual flight configuration flow diagram; Figure 5-19 shows a typical coldplate test system.)

A coldplate test program will be conducted by S&ID to produce coldplate units structurally strong enough to withstand the dynamic conditions during flight and to provide continuous thermal control of the electronic equipment operating in the command module throughout the Apollo mission.

5.3.3.2 Test Plan

5.3.3.2.1 Preliminary Tests

5.3.3.2.1.1 Mechanical Inspection. Each coldplate will be mechanically inspected for dimensional accuracy and surface flatness, for cleanliness, and for nonobstruction by foreign material in the passages. X-Ray inspection will be utilized where applicable.

5.3.3.2.1.2 Proof Pressure. Tests will be conducted as follows:

1. Install the coldplate in a test fixture so that a pressure of 90 psig may be applied internally to the coldplate.

2. Maintain 90 psig for 15 minutes and observe for any failures in the coldplate. If none appear, the test will be considered satisfactory and terminated.

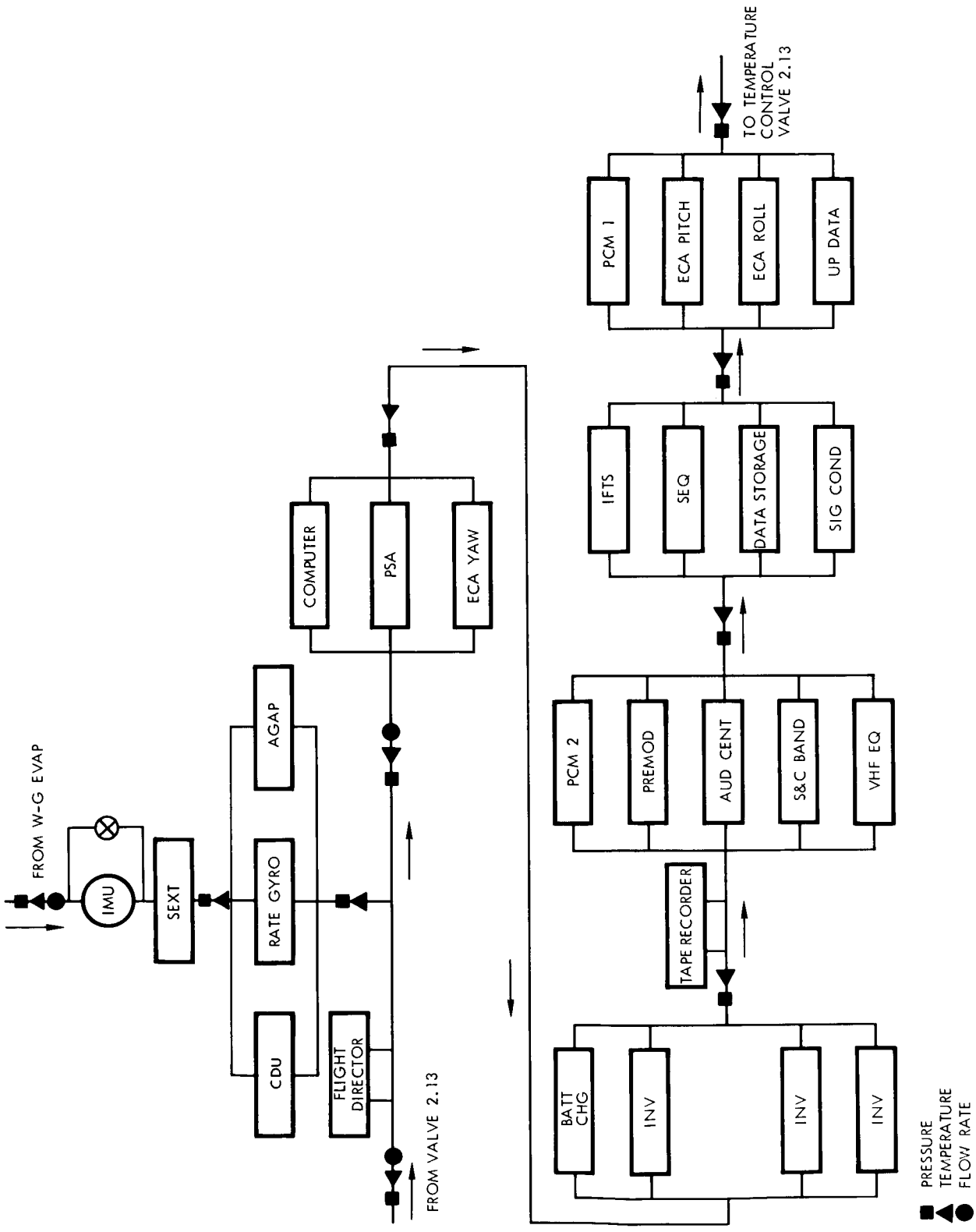


Figure 5-18. Cold Plate Flow Diagram

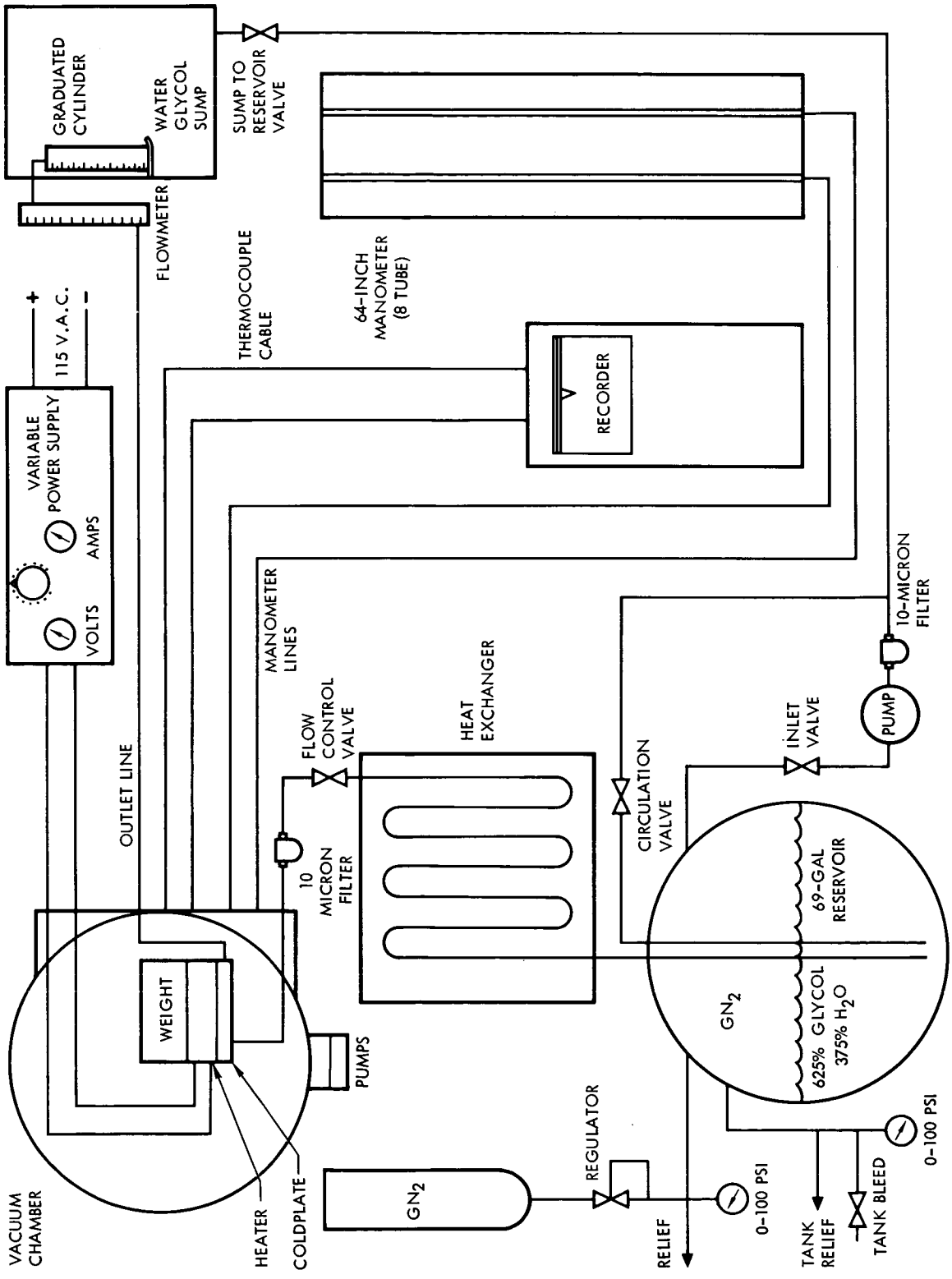


Figure 5-19. Typical Coldplate Thermal Test System

[redacted]

5.3.3.2.1.3 Leakage. Each coldplate that successfully passes the hydrostat test will be leak-checked with GN_2 as follows:

1. Attach a regulated GN_2 supply to the coldplate so that pressure may be applied to it internally.

2. Immerse the coldplate in water and pressurize it to 90 psig for 15 minutes.

3. Monitor for any leakage during this time. Any bubbles coming from within the coldplate will be considered a leakage. However, if no bubbles appear within 15 minutes, the test will be considered satisfactory and terminated.

5.3.3.2.2 Thermal Tests

5.3.3.2.2.1 Pressure Drop. The pressure drop across the coldplate will be determined by passing a mixture of inhibited water-glycol (62.50 parts by weight of ethylene glycol, 37.42 parts by weight of distilled water, 1.56 parts by weight of triethanolamine phosphate, 0.156 parts by weight of sodium mercapto benzo thiasole) through the coldplate at ambient room conditions as follows:

1. Connect a water-glycol circulating unit to both the inlet and outlet ports of the coldplate. Connect either manometer or differential pressure gage to these ports.

2. Circulate the water-glycol solution according to the following conditions:

   a. Through coldplate PN V16-614044, V16-614034, V16-614035, V16-614055, V16-614061. Water-glycol circulating conditions are as follows:

Run Number	Flow Rate (lb/hr)	Fluid Inlet Temperature (°F)
1	5	45
2	10	45
3	20	45
4	5	70
5	10	70
6	20	70
7	5	120
8	10	120
9	20	120

[redacted]

b. Through coldplate PN V16-614046, V16-614016, V16-614018, V16-614017, V16-614011, V16-4006, V16-614038, V16-614074, V16-614014. Water-glycol circulating conditions are as follows:

Run Number	Flow Rate (lb/hr)	Fluid Inlet Temperature (°F)
1	20	45
2	35	45
3	50	45
4	20	70
5	35	70
6	50	70
7	20	120
8	35	120
9	50	120

c. Through coldplate PN V16-614007, V16-614056, V16-614089, V16-614041, V16-614015, V16-614007. Water-glycol circulating conditions are as follows:

Run Number	Flow Rate (lb/hr)	Fluid Inlet Temperature (°F)
1	40	45
2	55	45
3	70	45
4	40	70
5	55	70
6	70	70
7	40	120
8	55	120
9	70	120

d. Through coldplate PN V16-614047. Water-glycol circulating conditions are as follows:

Run Number	Flow Rate (lb/hr)	Fluid Inlet Temperature (°F)
1	90	45
2	110	45
3	130	45
4	90	70
5	110	70
6	130	70
7	90	120
8	110	120
9	130	120

3. Determine the differential pressure between inlet and outlet ports at each flow rate by observing the manometer or the differential pressure gage.

4. The test will be considered complete when reproducible data ia obtained.

5.3.3.2.2.2 Thermal Gradient. A thermal gradient study of the coldplate will be conducted under ambient room conditions to determine thermal characteristics of the coldplate.

1. Attach thermocouples to the coldplate as shown in Figure 5-20.

2. Connect the coldplate to a water-glycol circulating unit having heating and cooling capabilities. (Install a glycol by-pass around the coldplate so that the water-glycol can circulate without having to pass through the coldplate.)

3. Install a pressure gauge to measure the inlet pressure to the coldplate, a differential pressure gauge to determine the pressure drop across the coldplate, and a flowmeter to measure the fluid flow from the outlet into a graduated container, for periodic checks of the flowmeter.

4. The flow rate will be the nominal value lb/hr indicated on the preceding tables for each group of coldplates and the fluid temperature maintained at 45°F and 120°F respectively.

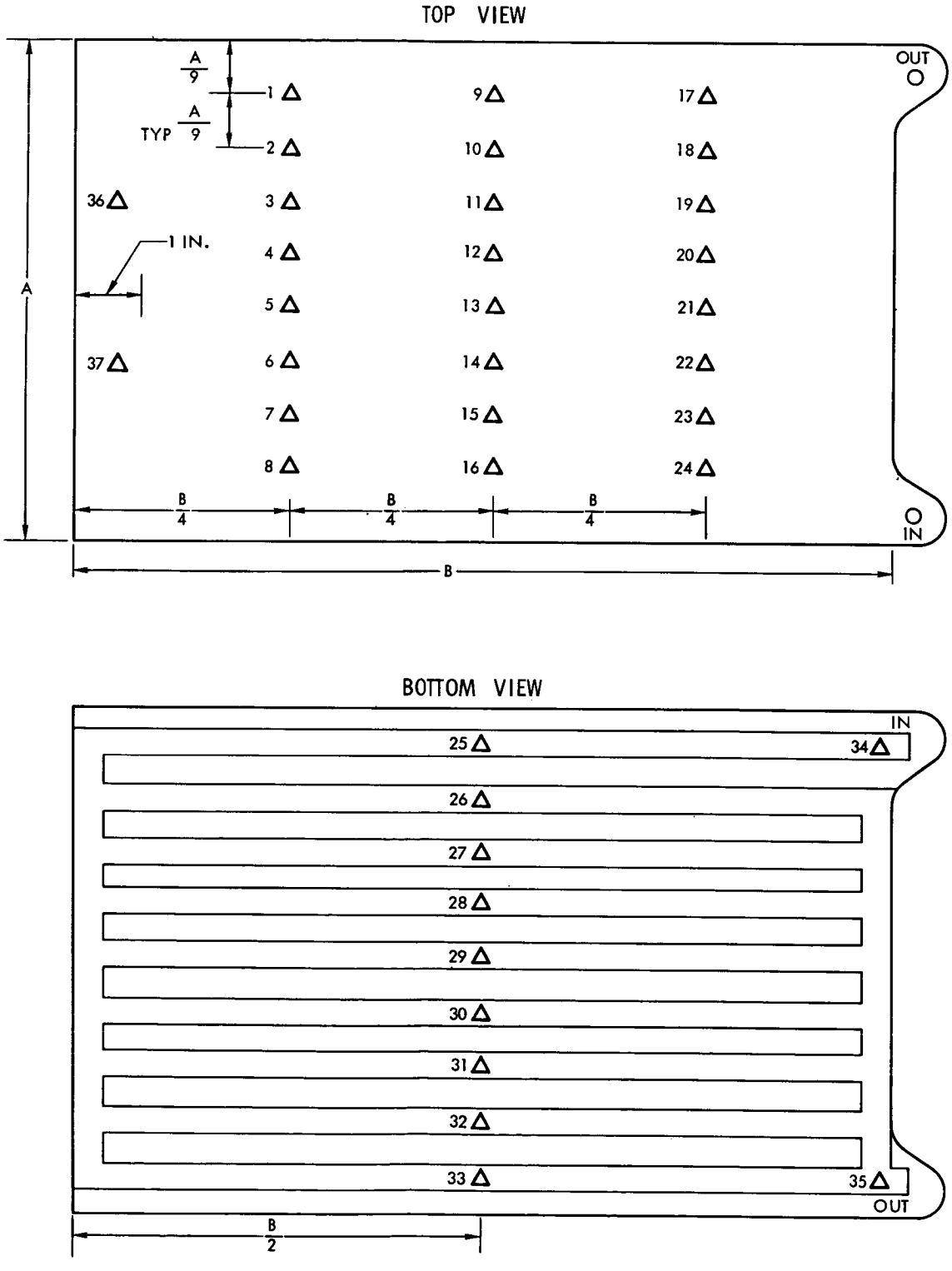


Figure 5-20. Typical Thermocouple Arrangement for Thermal Gradient Testing

5. After stabilizing the coldplate temperature, record the temperature value of each thermocouple. Continue the test for 20 minutes and note any changes in the temperature reading. Record all pressure readings and terminate the test when accurate data is obtained.

5.3.3.2.2.3 Thermal Conductivity. An interface material of copper foil wrapped silicon tubing soldered to a copper carrier sheet with a composite thickness of 0.156±0.003 inches will be used in the following manner:

a. Wipe the surface of the coldplate and copper carrier sheet with a clean cloth dampened with toluene and then immediately dry the surface with a clean cloth before the solvent evaporates.

b. Apply a thin layer (1 - 2 mils thick) of DC-340 (heat transfer grease) to the surface of the coldplate.

c. Place the thermal interface material on the coldplate, tube side up, and carefully apply pressure to the carrier sheet to insure good contact between surfaces. Care should be taken during this phase to avoid crushing or otherwise damaging the foil wrapped tubing.

The thermal conductivity of the coldplate will then be determined by using a simulated electronic box heat load.

1. Install the simulator on the coldplate compressing the interface material from a thickness of 0.156 inch to 0.130 inch. However, the load on the interface material may not exceed 10 psi. Attach thermocouples to the simulator to determine the heat input to the coldplate.

2. Place the test article in a vacuum chamber and connect a glycol cooling and circulating unit with flowmeter to inlet and outlet ports of the coldplate. (see Figure 5-19)

3. Install two thermocouples respectively on the inlet and outlet ports.

4. Lower the vacuum chamber pressure to 1×10^{-4} Torr (maximum pressure), start the water-glycol circulation unit, (make runs according to Tables 5-10 through 5-13) and apply the heat load. (The applied heat load will be one watt per square inch of plate area and evenly distributed over the entire surface.)

5. Allow the system to stabilize before recording any value and determine the heat absorbed by the water-glycol solution at each flow rate. Test may be terminated when accurate data is obtained.

5.3.3.2.3 Structural Tests

5.3.3.2.3.1 Pressure Cycling Test. The coldplate will be pressure-cycled 100 times with GN_2 to verify its capability to withstand varying pressures. The test is conducted as follows:

1. Attach a regulated N_2 supply to the inlet port and plug the outlet port.

2. Immerse and pressurize the coldplate in water from 0 to 60 psig. Repeat this for 100 cycles, each cycle to be completed within 30 seconds.

3. Monitor for leakage during the test. If after 100 cycles leakage does not appear, the test may be terminated.

5.3.3.2.3.2 Vibration Tests. The vibration test will be performed to verify the structural integrity of the coldplate. It is conducted by installing the coldplate on the vibration test fixture and vibrating it in each of the three major axes as follows:

Random Vibration. Linear increase from 0.01 g^2/cps at 5 cps to 0.06 g^2/cps at 75 cps. Constant at 0.06 g^2/cps from 75 cps to 2000 cps.

Keep the sweep frequency range 15 minutes per axis.

Record all resonant frequencies and the g loads at the resonant frequencies in each of three axes.

Inspect (visually) the coldplate for any damage or indication of failure, both during and after each test.

After completion of the vibration tests, leak-check the coldplate as in paragraph 5.3.3.2.1.3.

5.3.3.2.3.3 Acoustical Test. The acoustical tests verify that a coldplate will withstand the noise pressure levels that could be encountered on an Apollo mission. It is conducted as follows:

1. Install the coldplate in the acoustical chamber so that the sound pressure is uniform over all the surfaces. The natural frequency of the mounting assemblies should be less than 25 cps.

2. Apply the following noise levels at the corresponding octave bands: (The minimum time for sweeping the octave bands is 5 minutes.)

Octave Band	Noise Pressure Level (db)
11.2 - 22.4	113
22.4 - 45	121
45 - 90	127
90 - 180	127
180 - 355	126
355 - 710	127
710 - 1400	139
1400 - 2800	131
2800 - 5600	125
5600 - 11200	118
Over-all	137

3. Visually inspect the coldplate for any indication of failure during and after tests. Upon completion of the test, leak-check as in paragraph 5.3.3.2.1.3.

5.3.3.2.3.4 Acceleration Test. The acceleration tests will verify the coldplate's capability to withstand accelerations it might undergo during an Apollo mission.

1. Mount the coldplate in a test fixture that simulates an actual spacecraft installation.

2. Apply acceleration rate of 20 g's in both directions of each major axis for 5 minutes on each direction.

3. Visually inspect the coldplate for indications of failure during and after the test. After the tests are completed, leak-check the coldplate as in paragraph 5.3.3.2.1.3.

5.3.3.2.3.5 Shock Test. Shock tests will be performed to verify the coldplate's capability to withstand the impact of an earth landing.

1. Install the coldplate in a test fixture, mounting it from the same points from which it will be mounted in the spacecraft.

2. Apply a shock of 78 g's uniformly to the coldplate in a sawtooth wave form for 11±1 milliseconds. Three shocks will be applied in both directions along each of the three major axes. (Peak 78 g's, rise 11±1 ms, decay 1±1 ms.)

3. Visually check the coldplate for any evidence of failure during and after the tests. After the tests are completed, leak-check the coldplate as in paragraph 5.3.3.2.1.3.

5.3.3.2.3.6 Rupture Test. The purpose of this test is to determine the pressure at which the coldplate will rupture when subjected to internal hydrostatic pressure.

1. Place the coldplate in a suitable test fixture so that water pressure may be applied internally.

2. Connect a line to the inlet, apply water pressure, and allow all the air to bleed out.

3. Slowly increase the water pressure until the coldplate ruptures.

4. Record all data, including pressure level when rupture occurs, size and location of rupture, photographs, etc.

5.3.3.3 Network Functional Test

5.3.3.3.1 Equipment

1. Complete set of coldplates

2. Vacuum chamber having minimum dimensions of 5 ft in diameter and 7.5 ft in length and capable of maintaining 1×10^{-4} Torr.

3. Heat-load simulators to be mounted on the coldplates to simulate the electronic boxes.

4. Glycol-water circulating unit capable of supplying the glycol-water solution at flow rates of 0-225 pounds per hour at 40 F to 120 F.

5. Pressure gauges to measure glycol-water pressure at various points in the system.

6. Flow meter to measure the flow rate of the glycol-water in the system.

7. Temperature measuring equipment for measuring glycol-water, heat-load simulator, and ambient-air temperatures.

5.3.3.4 Facilities

The testing program will be conducted in S&ID's engineering development laboratories.

5.3.3.5 Schedules

The schedule for the testing program is shown in Figure 5.21.

The schedule for the ECS radiator manufacturing and test plan is shown in Figure 5-22.

5.3.4 Boilerplate Breadboard Cooling System Tests

5.3.4.1 Test Objectives

The objective of the individual component tests is to verify that each component will perform within its specified operating limits and will meet the requirements of the boilerplate mission, which include, e.g., pressure drop, power consumed, temperature control, and vibration.

The objective of the system test is to verify that the components will function properly when installed in a simulated boilerplate cooling system and subjected to a simulated mission with respect to C/M pressure and heat loads.

5.3.4.2 Test Plan

5.3.4.2.1 Individual Component Tests

1. The motor pump (ME 281-0011) will be placed in a water-glycol system capable of measuring the flow rate of the fluid through the system. The differential pressure across the pump and the power required to operate it will be measured. The pump will be operated in ambient and vacuum conditions. Vibration tests will be performed with the pump operating under load.

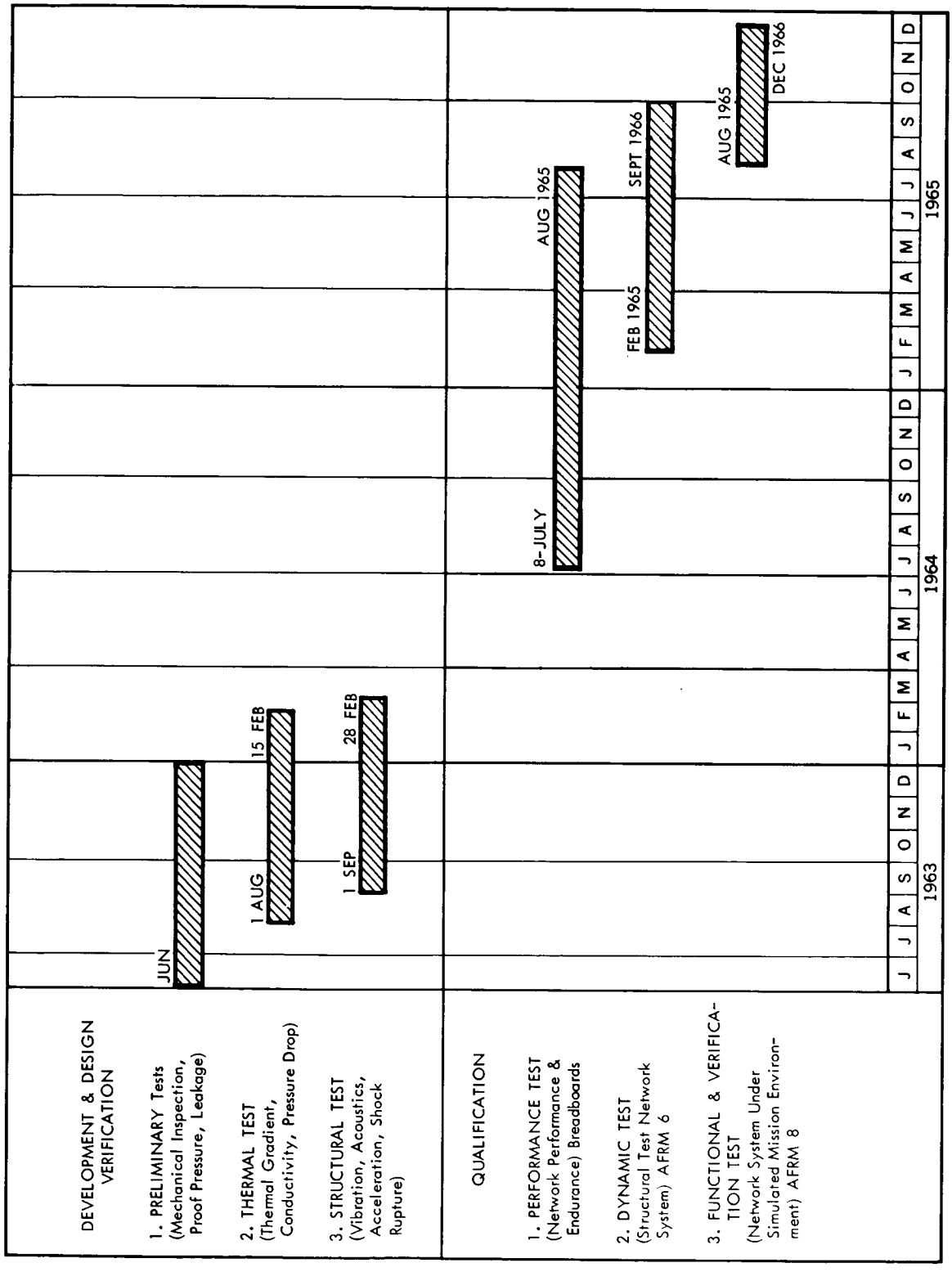


Figure 5-21. Schedule for Coldplate Development and Qualification Testing

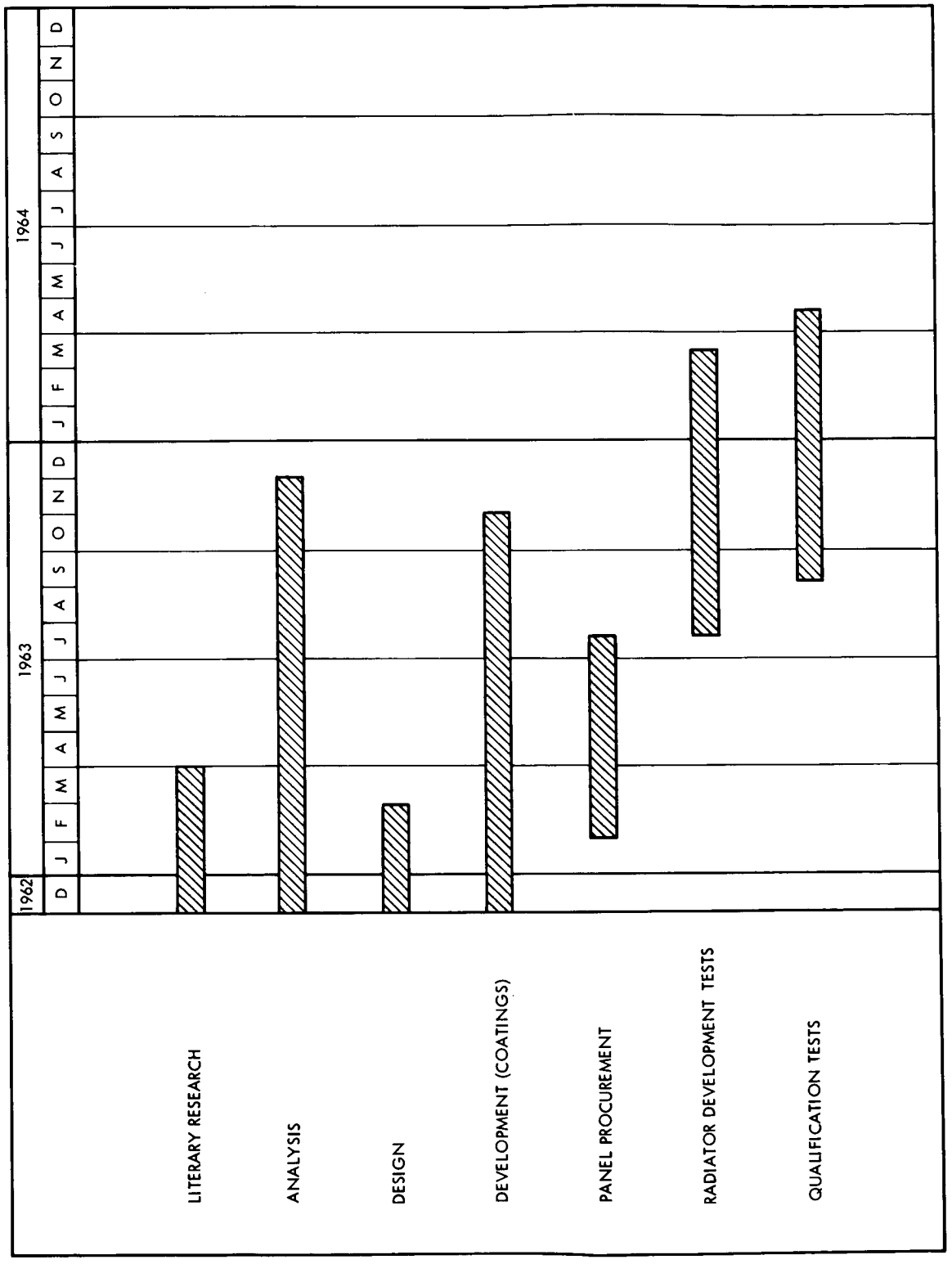


Figure 5-22. Plan for Radiator Manufacturing and Testing

2. The thermal control valve (ME 284-0069) will be installed in a water-glycol system which will have warm and cold reservoirs. The temperature of the cold reservoir shall be +10 F and that of the warm reservoir shall vary between +35 F and +60 F. Warm fluid will be pumped into the valve at a flow rate of 3 gpm and mixed with cold fluid from the cold reservoir. The fluid will then be discharged from the valve at a regulated temperature between +35 F and +42 F. The pressure drop across the valve will be measured at the above flow rate at various inlet temperatures between +35 F and +60 F. Vibration tests will be performed with the valve filled with fluid.

3. The heat exchanger (ME 362-0004) will be connected to a water-glycol circulating system capable of supplying a flow of 3 gpm. The pressure drop across the heat exchanger will be measured at the above flow rate with the by-pass valve in both the open and closed position. Electrical power will be applied to the heat exchanger to operate the fan and solenoid valve. The thermostat will also be checked for proper operation. Vibration tests will be performed with the fan operating and a water-glycol flow through the core of 3 gpm.

5.3.4.2.2 System Test. A simulated boilerplate cooling system will be fabricated with the tubing lengths, bends, and component elevations as similar to the actual system as possible. The system will be placed in a vacuum chamber and instrumentation installed to measure temperatures and pressures at various locations in the system. Also, the power required to operate the pump and heat exchanger fan will be measured. Heat loads will be applied to the coldplates and vacuum chamber atmosphere. A simulated mission will be run with the vacuum chamber pressure lowered at the same rate as the pressure in the command module. Also, the heat loads will be varied to simulate the actual loads. After the test the components will be inspected for any discrepancies caused by the test.

5.3.4.3 Equipment

1. A Boilerplate 13 simulated cooling system made up of production components and tubing of the same size, lengths, and bends as used in the Boilerplate.

2. A cooling and circulating unit capable of cooling 15 gallons of water-glycol to a temperature of +10 F and supplying it to a component at a flow rate of 2-5 gpm.

3. A vacuum chamber with a minimum volume of 200 cubic feet and capable of maintaining a pressure of 1×10^{-4} Torr.

4. A vibration test fixture capable of vibrating the individual components, which have a maximum weight of 30 pounds, at the levels called out in the test plan. Also, adequate instrumentation will be required to measure the vibration levels imposed.

5. Temperature measuring equipment, including thermocouples and recorders capable of measuring temperatures between +10 F and 225 F with a maximum tolerance of ±1 F.

6. A flowmeter capable of measuring water-glycol flow rates between 2 and 5 gpm at temperatures between +10 F. and +100 F.

7. Various pressure and ΔP gages with a maximum tolerance of ±1 percent.

8. Heat load simulators capable of supplying a 2500-watt heat load to the atmosphere and 585 watts to a set of coldplates. A wattmeter shall be utilized to verify the heat input during test runs.

5.3.4.4 Facilities

The testing program will be conducted in the S&ID Engineering Development Laboratories.

Schedules

The schedule for the testing program of Boilerplate 13 cooling system is shown in Figure 5-23.

5.3.5 Waste Management System Test

5.3.5.1 Objective

The system will be subjected to natural and induced environmental conditions in order to verify design requirements during installation, transportation, handling, storage, and simulated Apollo mission profiles. To evaluate and demonstrate the capability of the ECS waste management system to provide ventilation for the waste, refuse and storage compartments and to provide for the control of gaseous, solid, and liquid wastes within

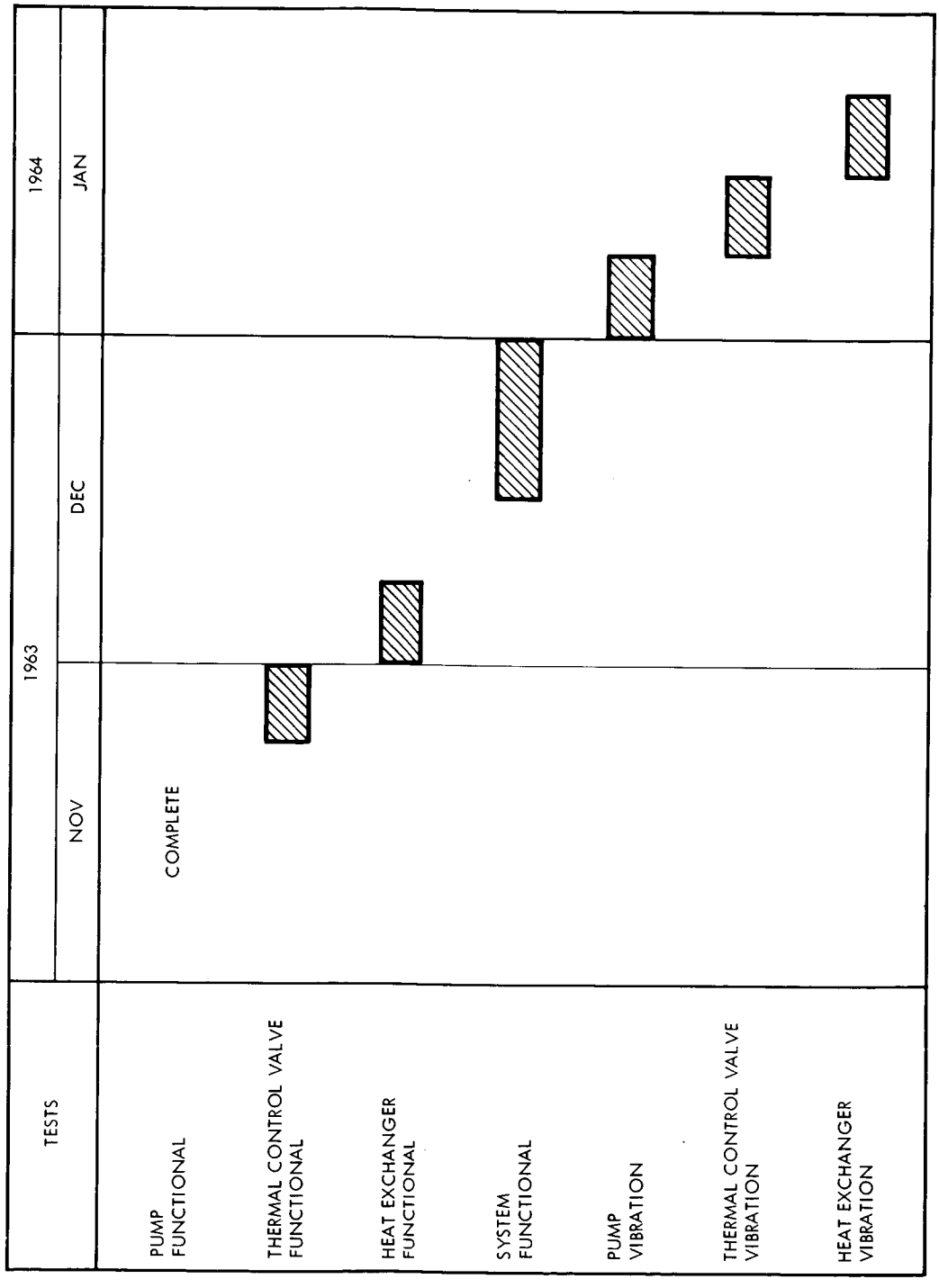


Figure 5-23. Boilerplate 13 Cooling System Testing Schedule

the command module. The waste management system shall also provide disposition of gaseous waste to the ECS for processing, operate for a minimum of 14 days without supply and be able to withstand the dynamic stress to be encountered during the Apollo mission.

5.3.5.2 Test Plan

One complete system shall be utilized for this test program. A schematic drawing of the test specimen is shown in Figure 5-24. It will be built of components that previously have met all acceptance test requirements of S&ID Procurement Specifications. After testing is completed, the tested system shall be returned to the ECS test unit for final disposition. A component that has failed shall be processed as indicated in Paragraph 5.3.5.2.3.5 prior to submittal for disposition.

5.3.5.2.1 Design and Performance Requirements. The waste management system (Figure 5-24) is designed to provide ventilation for the food and waste, refuse, and personal hygiene equipment storage compartments and to provide for the control of gaseous, solid, and liquid wastes within the command module. The WMS shall also provide disposition of gaseous waste to the ECS for processing, operate for a minimum of 14 days without supply and be able to withstand the dynamic stresses to be encountered during the Apollo mission.

5.3.5.2.2 Test Sequence. The system shall be tested in the sequence listed below:

Component Operation

Functional Operation

Vibration

Acceleration

5.3.5.2.3 Test Conditions. Unless otherwise specified herein, all tests shall be performed at an atmospheric pressure between 0 inches and 12.20 inches of mercury, a temperature between 40 F and 75 F, and a relative humidity of not more than 70 percent. Data obtained at other atmospheric conditions shall include necessary correction factors for instrument readings.

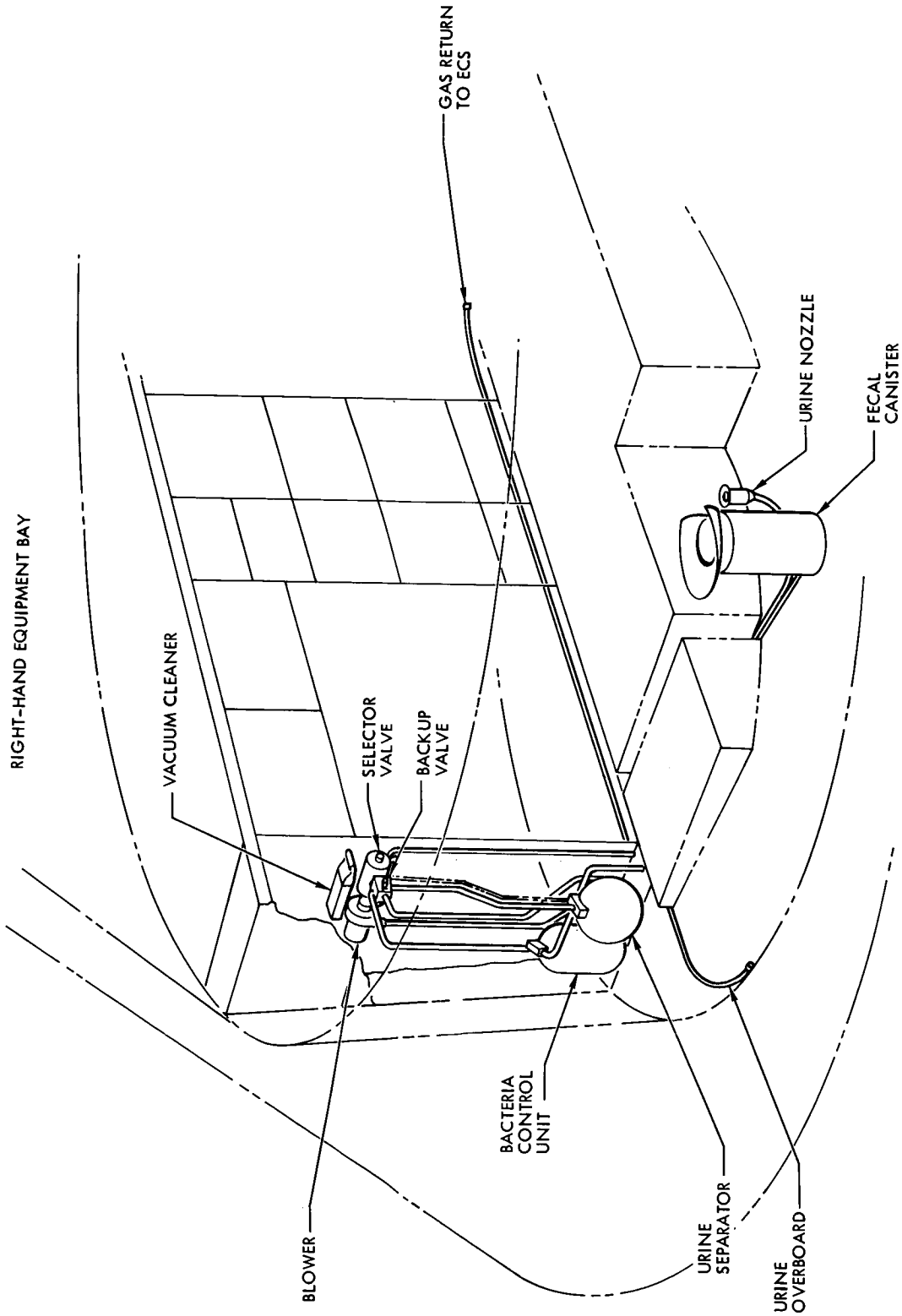


Figure 5-24. Waste Management Installation

[redacted]

5.3.5.2.3.1 Instrumentation and Installation of Test System. The test system shall be instrumented and installed as shown in Figure 5-25. Test chamber will provide adequate internal and external terminals to permit instrumentation lines for the system.

5.3.5.2.3.2 Pressure. Leak-tight lines shall be connected for both the fluid and air lines. Pressure sensing instruments shall be installed as per Figure 5-25.

5.3.5.2.3.3 Temperature. Copper constantan thermocouples shall be installed as per Figure 5-25.

5.3.5.2.3.4 Flow. Flowmeters shall be installed per Figure 5-25.

5.3.5.2.3.5 Inspection and Failure Criteria. At the end of each test the test system will be visually inspected and a record made of any damage resulting from the test. Damage, deterioration, excessive corrosion, or damage in performance that could in any manner prevent the test system from meeting operational requirements shall provide reason to consider the test item as having failed to withstand the conditions of the tests. After a failure, the test system, with the approval of ECS, may be adjusted or repaired and testing continued.

5.3.5.2.4 Vibration Test. Place test system with support on a test fixture for vibration along each of the lateral axes and along the longitudinal axis. Subject the system to the following conditions along each axis. Scan the frequency range from 5-2000 (cps) in 30 minutes (scanning twice in each of the three major axes, noting the frequency of all resonant points).

Frequency (CPS)	Vibration
5-10	0.030 inch D.A.
10-20	±1.6 G
20-63	0.075 inch D.A.
63-2000	±15 G

Subject resonant frequency will be applied for 5 minutes of vibration in each of the three major axes at the following conditions: 5-20 CPS at 1.6 G, 20-63 CPS at 0.07 inch D.A. Perform leakage test upon completion of vibration test.

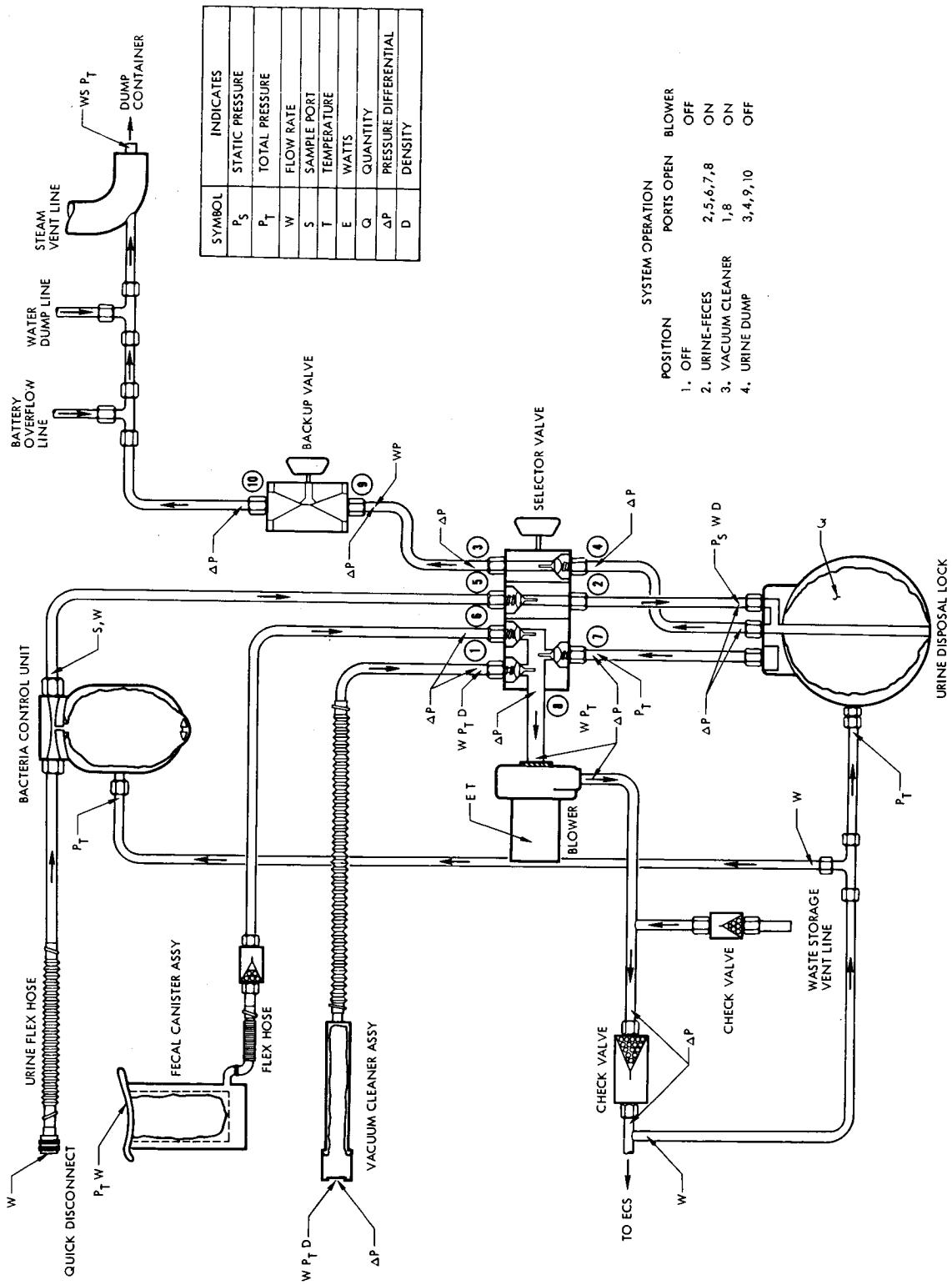


Figure 5-25. Waste Management System

[redacted]

5.3.5.2.5 Acceleration Test. Place test system on test fixture for acceleration application along the major lateral axis in both directions and to permit application of acceleration along the longitudinal axis (flight axis) in the flight direction.

Apply acceleration of 25g for 10±1 minutes along each axis. Perform leakage test upon completion of acceleration test.

5.3.5.3 Equipment Requirements

The items listed and described below represent the major components needed for the component and system testing of the WMS.

1. Space simulation chamber of sufficient capacity to hold WMS.
2. A 100 percent oxygen source
3. Instrumentation and measuring equipment consisting of pressure gauges, differential pressure gauges, flowmeters and an electrical power source for 10-watt blower.

5.3.5.4 Facilities

The waste management system test program will be conducted at S&ID facilities.

5.3.5.5 Test Schedule

The schedule for the testing program is shown in Figure 5-26.

[redacted]

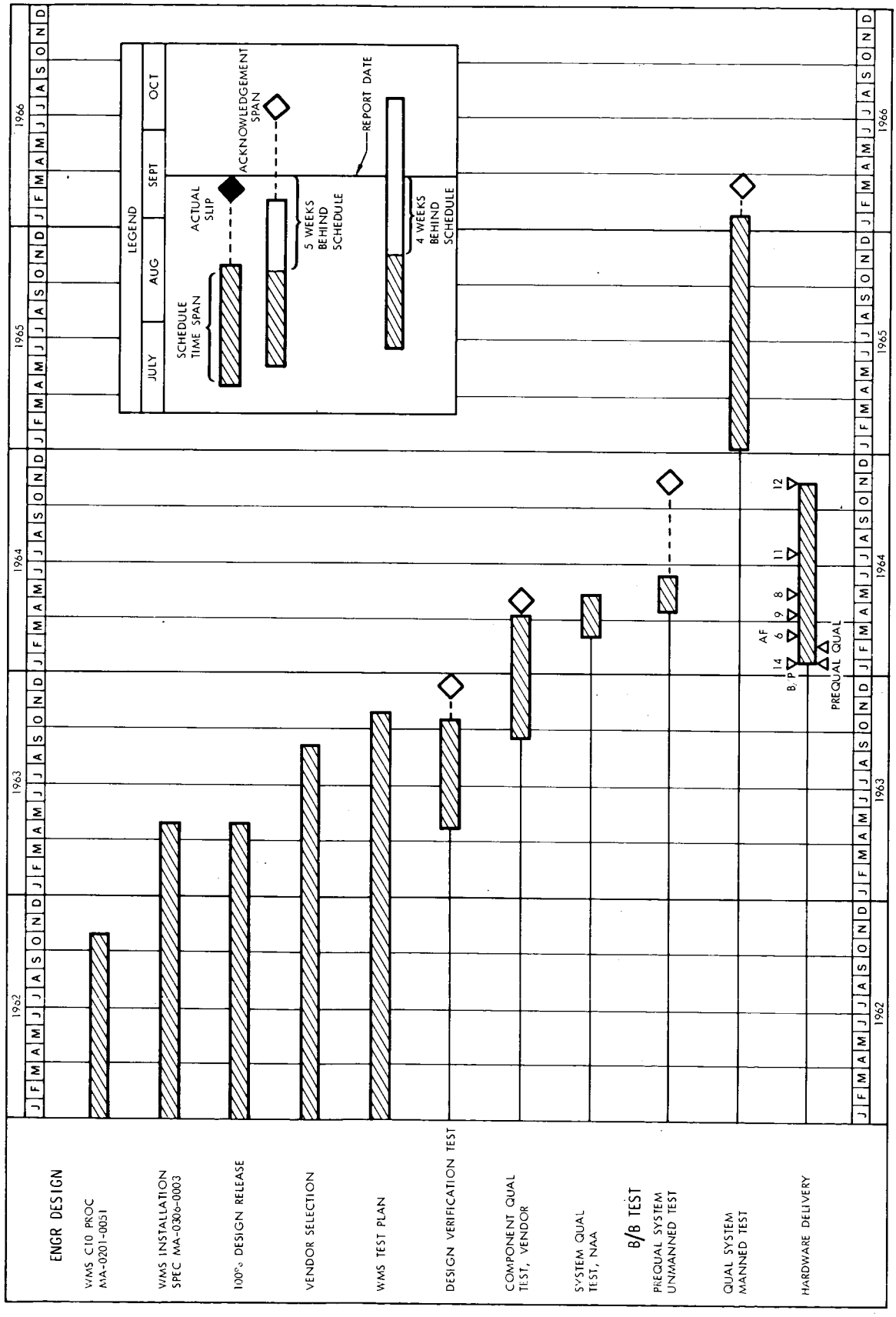


Figure 5-26. ECS Waste Management System Schedule

6.0 ELECTRICAL POWER SYSTEM*

6.1 SCOPE

Development, design, verification, evaluation, and qualification testing of the electrical power system (EPS) components, subsystems, and systems will be performed jointly by the subcontractor and the prime contractor. The test program includes functional, as well as environmental tests, designed to establish reliable hardware and reliable systems.

6.2 SUBCONTRACTOR TEST PLAN

6.2.1 Fuel Cells (Pratt & Whitney Aircraft)

6.2.1.1 Objective

P & WA is responsible for the design, development, and qualification of fuel cell modules for Apollo missions.

6.2.1.2 Test Plan

P & WA will conduct a multiphase program to encompass design development, component testing, multiple cell testing, single module testing, and qualification testing. During the design development phase, P & WA will develop a design and build multiple cell modules that will produce electrical power for a complete Apollo mission and provide potable water as a by-product suitable for astronaut consumption. Development testing will be performed on components (electrodes, pump separators, by-pass valves, etc.) to the design, off-design, and durability requirements. Self-induced and externally-induced failure modes also will be investigated. Single-module testing will provide data on thermodynamic and module output performance characteristics of the operating system. Qualification testing is performed to establish confidence in the capability of fuel cell power plants to function as a system under selected environments. Details of individual tests can be obtained from the Pratt & Whitney test plan (PWA 2054).

6.2.2 Umbilicals (Subcontractor to be selected)

*Entire section reissued

[redacted]

6.2.2.1 Objectives

The subcontractor will be responsible for development and qualification of all umbilicals and pressure-barrier feed-through connectors used in the Apollo vehicle. The objectives of the subcontractor test program are:

1. To determine the effect of high-differential temperatures on the sealed insert
2. Guarantee pressure seals during all environments expected in the Apollo mission
3. Assure compliance with specified electrical characteristics and mechanical requirements

6.2.2.2 Test Plan

The subcontractor will conduct the following program to verify the design and establish reliability of the umbilicals and pressure-barrier feed-through:

1. Verify electrical and physical compatibility with spacecraft requirements
2. Verify pressure-barrier feed-through throughout the low-temperature, high-temperature, pressure range, acoustic vibration, shock, and acceleration environments

6.2.2.3 Equipment

The following test equipment will be used on this phase of the program:

Vibration machine
Temperature-altitude chamber (400,000 feet)
Acoustic-vibration chamber
Shock tower
Centrifuge
Megger and hypot

6.2.3 Entry and Postlanding Batteries (Eagle-Picher)

6.2.3.1 Objective

The objective of Eagle-Picher's test program will be to verify the design of the zinc-silver oxide batteries and qualify them per S&ID procurement specification MC 461-0003B.

[redacted]

The design effort will be centered around packaging, as the cells themselves are standard units. Pressure tests of the case to determine rupture pressure, seal qualities, and positive pressure release or venting are most critical.

Long term tests shall determine effects of temperature variations and activated cell (discharged) storage on cell separators and battery capacity.

6.2.3.2 Test Plan

The subcontractor will be responsible for conducting sealing tests and simulated battery over-gassing tests. In addition, Eagle-Picher will operate the batteries in the various environments applicable to the battery including: low and high temperature, temperature shock, altitude, shock, vibration, acceleration, humidity, life test, and leak tests.

Storage tests in both the charged and discharged (activated) conditions will also be conducted to determine effects on capacity.

6.2.3.3 Equipment

The following equipment will be required:

Low-high temperature chamber
Altitude chamber
Vibration machine
Shock tower
Centrifuge
Miscellaneous equipment
Humidity chamber

6.2.4 Pyrotechnic Batteries (Electric Storage Company)

6.2.4.1 Objective

The subcontractor will verify the design of the zinc-silver oxide batteries and qualify them per S&ID procurement specification MC 461-0007.

The design effort will be centered around packaging. Pressure tests of the case to determine rupture pressure, seal qualities, and positive pressure release or venting are most critical.

Long term tests shall determine effects of temperature variations and activated cell (discharged) storage on cell separators and battery capacity.

[redacted]

6.2.4.2 Test Plan

The subcontractor will be responsible for conducting sealing tests and simulated battery over-gassing tests. In addition, the subcontractor will operate the batteries in the various environments applicable to the battery including: low and high temperature, temperature shock, temperature altitude, shock, vibration, acceleration, humidity, life test, and leak tests.

Storage tests in both the charged and discharged (activated) conditions will also be conducted to determine effects on capacity.

6.2.4.3 Equipment

The following equipment will be required:

Low-high temperature chamber
Altitude chamber
Vibration machine
Shock tower
Centrifuge
Humidity chamber
Miscellaneous equipment

6.2.5 Static Inverter (Westinghouse)

6.2.5.1 Objective

The objective of the Westinghouse test program is to verify the design of and qualify the inverter per S&ID procurement specification MC 495-0001D.

More specific objectives are to develop and test the solid-state inverter (115/200-volt, 400-cps, 3-phase) possessing minimum harmonics and RFI generation, stable voltage and frequency characteristics, maximum efficiency, and minimum size and weight. These characteristics will be optimized under temperature variations and load cycling. Operational temperatures are to be held below 120° C.

6.2.5.2 Test Plan

Westinghouse shall perform development tests of circuits and evaluation of components as required to minimize size, weight, harmonic distortion, acoustic noise generation and RFI generation, and to assure reliability. In addition, Westinghouse shall determine effects of coolant temperature variations and of other environments such as high and low temperature, altitude, shock, vibration, acceleration, radio frequency and electromagnetic interference, life test, leak tests and off-limit load tests.

[redacted]

6.2.5.3 Equipment

The following test equipment is required:

Temperature chamber
Altitude chamber
Vibration machine
Shock tower
Centrifuge

6.2.6 Battery Charger (International Telephone and Telegraph Corp.)

6.2.6.1 Objective

The objective of ITT's development test plan is to verify and improve the design of and qualify the charger per S&ID procurement specification MC 461-0002B.

The tests will be directed toward increasing efficiency and regulation and reducing size, weight, and RFI generation, as well as assurance that the charger cannot overcharge the battery.

6.2.6.2 Test Plan

The subcontractor shall perform developmental tests of components and circuits to reduce weight, acoustical noise generation, RFI generation, RFI susceptibility, sources of RFI, and the number of components as well as to increase efficiency and regulation. Tests shall also be performed to assure current limiting ability of circuitry and the stability of charging voltage cut-off during expected environments of high and low temperature, altitude humidity, shock, vibration, life cycle, off-limit tests, and acceleration.

6.2.6.3 Equipment

The following equipment will be required:

Temperature chamber
Altitude chamber
Shock tower
Vibration machine
Centrifuge
Humidity chamber
Miscellaneous equipment

[redacted]

[redacted]

6.3 S&ID TESTS OF NAA OR SUBCONTRACTOR COMPONENTS

6.3.1 Batteries, Charger, and Inverter

6.3.1.1 Objective

S&ID will perform evaluation tests of the major distribution subsystem components on a breadboard level. The breadboard approach will enable S&ID to determine early in the program if the design is sound and also to design and evaluate proposed circuit variations.

The subcontractors will perform qualification tests of final hardware, but S&ID will in the course of the electrical power system compatibility tests evaluate the performance of the operational components. Some specific objectives of the electrical power system tests are as follows:

1. To determine parasitic losses of the distribution subsystem
2. To determine transient response
3. To determine efficiency and regulation of inverters and battery chargers
4. To determine charge and discharge characteristics of zinc-silver oxide batteries
5. To evaluate recharge degradation of batteries
6. To determine compatibility with fuel cell power supply

6.3.1.2 Test Plan

Breadboards of the EPS will be used early in the program. Component parts will be installed in the breadboard as they are qualified.

System compatibility tests utilizing inverters, batteries, chargers, fuel cells, umbilicals, and the complete distribution system will provide short-circuit data, overload characteristics, operation of the low-voltage circuit, and charge and recharge characteristics of the batteries.

Prior to house spacecraft tests, electromagnetic interference will be minimized through preliminary analysis and system compatibility tests. The electrical power system will be available in the house spacecraft for compatibility tests with the spacecraft electronic systems.

[redacted]

6.3.1.3 Equipment and Facilities Required

The equipment and facilities will be provided by S&ID Engineering Development Laboratory.

6.3.1.4 Development Schedules

The development test schedules for the batteries, battery chargers, and inverters are presented in Figures 6-1, 6-2, and 6-3.

6.3.2 Fuel Cell Test Plan

6.3.2.1 Scope

Early experimental testing initiated at Pratt & Whitney facilities is to supplement related fuel-cell system testing now under way and will be concerned only with tests on single modules. Tests will be conducted by the Engineering Development Laboratories at S&ID, Downey, California, to determine the effects of operating variables on fuel cell performance, establish the limits of performance of the powerplants and initiate further evaluation of fuel cell performance to determine such parameters as thermodynamic characteristics, load sharing, reactant regulation, etc. The Apollo electrical power systems group will coordinate all phases of the test.

6.3.2.2 Objectives

Prime objectives to be accomplished during the performance of evaluation tests are as follows (See Table 6-1 and 6-2):

1. To determine minimum and maximum power output
2. To obtain specific fuel consumption, pressure, temperature, water production, water PH data, and determine water purity
3. To determine start-up characteristics
4. To determine transient response time to load variations
5. To assess performance of regulators, heat exchangers, water separators, and other mechanical systems
6. To determine radiator performance and heat-dissipation characteristics
7. To determine start-hold and stop capabilities

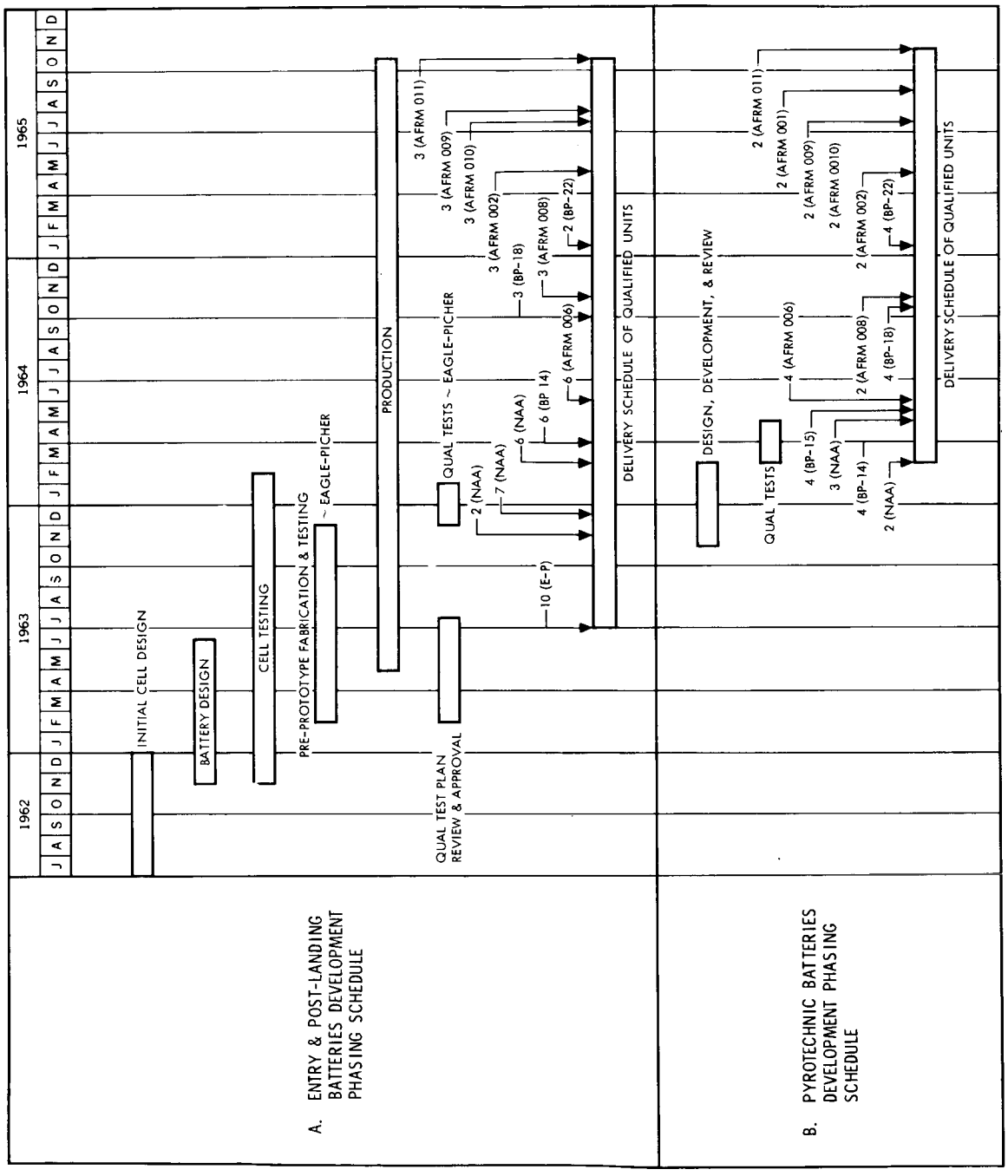


Figure 6-1. Apollo Battery Development Phasing Schedule

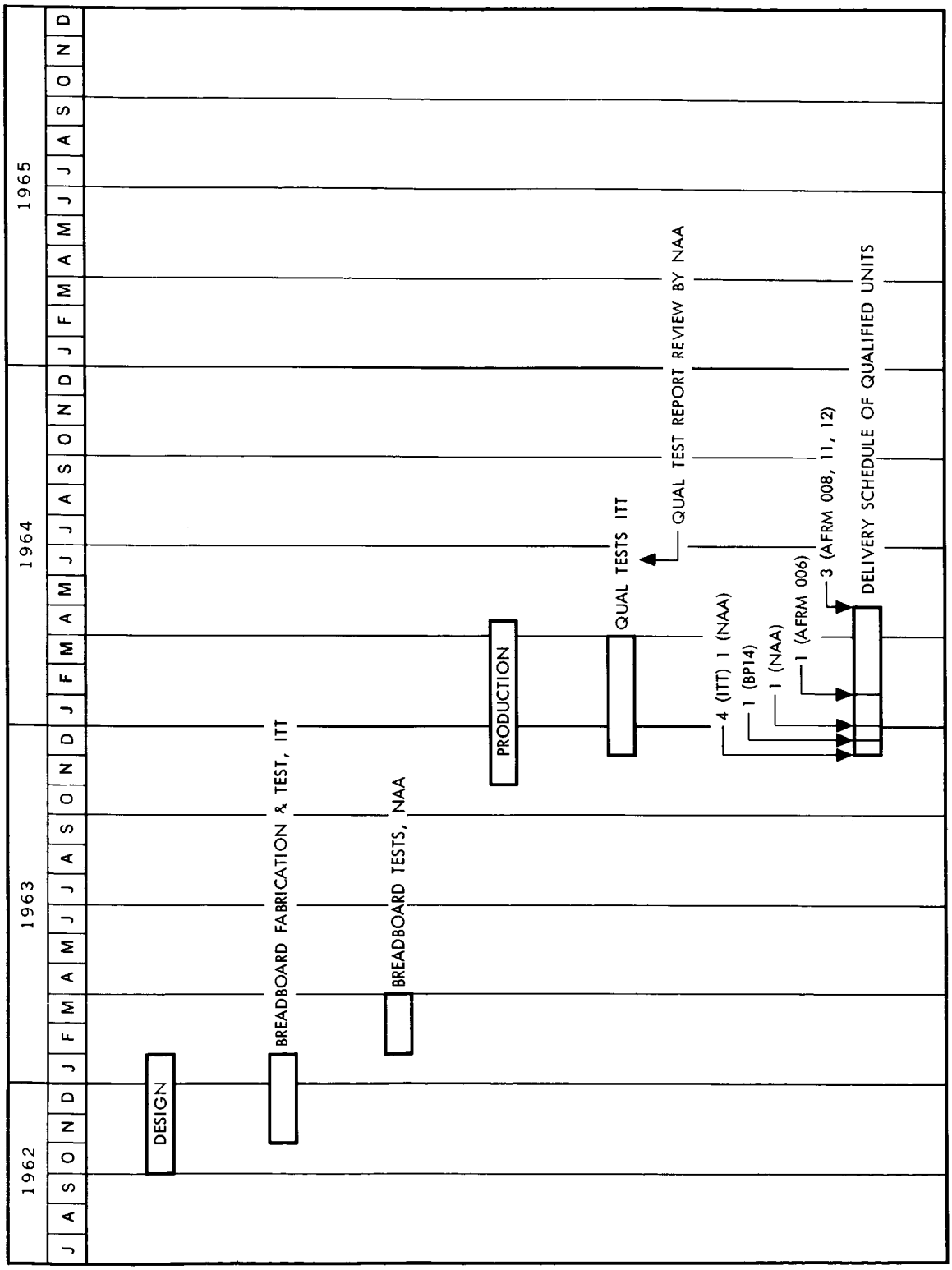


Figure 6-2. Apollo Battery Charger Development Phasing Schedule

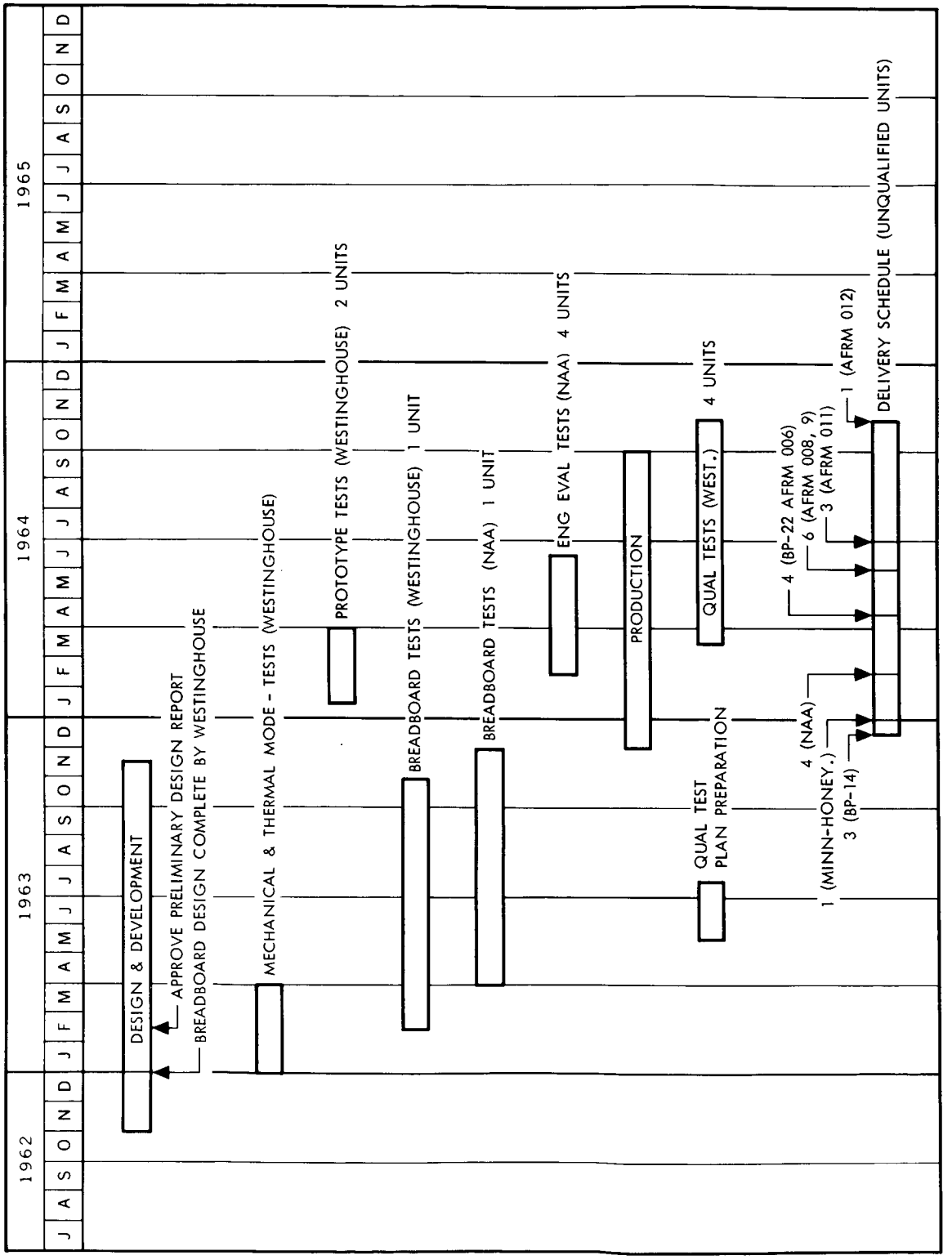


Figure 6-3. Apollo Static Inverter Development Phasing Schedule

Table 6-1. Fuel Cell Tests

Test Service Module Evaluation	Test Description	Items to be Monitored
Leakage	Pressurize module utilizing He for H_2 and N_2 for O_2	Pressure
Insulation resistance	Measure the electrical resistance of thermal insulating materials	Megohms
Start-up	During preheat cycling, evaluate power required, the hot N_2 purge requirement, terminal voltage, and module temperature as reactants are applied	Volts, a-c current, watts, time, and module temperature
Voltage regulation	Apply resistive loads in steps from zero to maximum and measure all values as steady-state condition	Volts, d-c current, and all module instrumentation
H_2O production	Evaluate water production, PH, purity and pump power. Glycol and water separator pumps are on the same line. Therefore, both are checked concurrently.	PH meter, sampling equipment, and flow meter
Reactant utilization	Effect of initial reactant temperature and pressure on power output.	Voltage, current, and all powerplant instrumentation points
Heat rejection	Determine total heat rejection of the complete fuel cell powerplant system.	Glycol flow, glycol pressure, and glycol temperature

Table 6-1. Fuel Cell Tests (Cont)

Test Service Module Evaluation	Test Description	Items to be Monitored
Parallel module operation load cycling	Vary loads and observe regulators for hunting and overshoot	Each module, volt, current, reactant pressure, and module instrument points
Transient response	Change resistive load of various magnitudes, constantly monitoring voltage and current	Volt, time, current, and all module instrument points
Load sharing	Load sharing for various loading conditions and effect on load sharing by incomplete purging, module temperature, and pressure variations	Voltage, current, and all module instrumentation points
Heat rejection	Determine total heat rejection of the complete fuel cell power system	Glycol flow, glycol pressure, glycol temperature, Voltage, Current, and H_2
EDS and EPS	Determine load sharing between fuel cell and batteries	Voltage, battery current, and fuel current
Failure mode	Determine the time that modules will operate under various loads when auxiliary pumps are not operational	Volts, dc, volts, ac, and time
ECS and EPS	Maximum oxygen flow rate	Volt, Current, and Oxygen
EPS - ECS	Man-rating of ECS Chamber	All powerplant instrumentation

Table 6-2. Heat Rejection Tests

Type of Test	Test Plan	Range of Values	Accuracy
Radiator performance	Determine inlet and outlet temperature and heat dissipation in thermal vacuum chamber	10^{-4} mm Hg	
Radiator inlet temperature	Measure glycol inlet temperature	0 to 250 F	±5 degrees
Radiator outlet temperature	Measure glycol outlet temperature	-35 to +240 F	±5 degrees
Radiator temperature	Determine equilibrium temperature at minimum and maximum heat load under simulated space environment		
Radiator pump power	Determine power consumption at minimum and maximum heat load conditions	0 to 30 watts	
Radiator transients	Verify that fuel radiator response is rapid enough to insure no detrimental effect on fuel-cell system power output in all external environments	-30 to +250 F	

[redacted]

8. To evaluate parallel operation

9. To verify start, stop, and operating procedures

6.3.2.3 Test Plan

S&ID tests will be divided into categories reflecting the specialized facility requirements, rather than listing categories being performed.

6.3.2.3.1 Engineering Development Laboratory. Three prototype fuel-cell power plants, supercritical reactants, and all off-the-shelf components (resistors, regulators, heat exchangers, etc.) will be utilized to evaluate the fuel-cell power plant functional characteristics and to compile data to finalize design of support components. During the final stages of the test program, the EPS and ECS subsystems will be integrated to determine and correct any degrading interaction that may result from the combined systems. Some specific objectives of the fuel-cell tests are as follows:

1. To verify the operational characteristics of a single module powerplant.

   To demonstrate the characteristics of parallel powerplant operation.

3. To demonstrate compatibility of fuel cells and battery parallel operation.

4. To demonstrate compatibility of fuel cells and inverters.

5. To demonstrate compatibility of fuel cells with storage dewars.

The EDL should plan to complete this test effort within the P&WA design objective of 400 operational hours, and within 12 powerplant starts and stops.

6.3.2.3.1.1 Test Procedure

1. Visually inspect the test units to assure that no deformation occured as a result of shipping, handling, or storage.

2. Test for continuity across each electrically excited component.

3. Test for continuity between each electrically excited component and module case, recording all resistance values below 100,000 ohms.

[redacted]

4. Apply 100 volts to all ac excited components. For motors, connect phases to a common junction and record values between neutral and powerplant case.

5. Apply 500 volts to all dc excited components. Record the values between powerplant case and the total number of wires originating from a single component.

6.3.2.3.1.2 Operational Performance (Single Powerplant). In this portion of the test only (single powerplant), all electrically excited components within the fuel cell are to be operated from external power sources. For the purpose of this test, standard conditions will be defined as the unit operating at a sea level environment and tested as follows:

6.3.2.3.1.2.1 Pressure

1. Oxygen (gas) 900 psia

2. Hydrogen (gas) 250 psia

3. Nitrogen (gas) 1500 psia at operating temperature

4. Ethylene glycol (liquid) 65 psia circulating with a 15 psig pressure differential across the heat exchanger.

5. 35 psia head pressure on water discharge line.

6.3.2.3.1.2.2 Temperature

1. Apply 80 volts rms, 60 cycle to powerplant internal heaters and record surface temperature rise versus time until the indicated temperature is approximately 380 F.

2. With the powerplant surface temperature reading approximately 380 F, apply a 570 watt resistive load to the powerplant output voltage. Continously record voltage output and surface temperature rise versus time until the surface temperature is stabilized at 460 F.

6.3.2.3.1.2.3 Electrical Performance

1. Voltage Output Versus Load at 460 F. With the unit operating at a stabilized condition (Paragraph 6.3.2.3.1.2.2) apply a 520 watt resistive load to the powerplant output, recording voltage output and current. Increase power at 200 watt increments, recording voltage, current and watts.

2. Voltage Output Versus Load at 490 F. With the unit operating at 460 F surface temperature and a 520 watts resistive load, increase voltage to powerplant internal heaters until a stabilized module surface temperature of 490 F is obtained. Starting at 520 watts, increase power at 200 watt increments, recording voltage, current and watts.

3. Voltage Output Versus Load at 435 F. With the unit operating at 460 F surface temperature and at 520 watts resistive load, reduce voltage to powerplant internal heaters until a stabilized surface temperature of 435 F is obtained. Starting at 520 watts, increase power at 200 watt increments, recording voltage, current and watts.

4. Voltage Output Versus Load at Reduced Reactant Pressures. With the powerplant operating at 460 F surface temperature and at 520 watts resistive load, reduce the reactant pressure to 150 psia for oxygen and 100 psia for hydrogen. With the reactant pressure and temperature (460 F) stabilized, perform voltage output versus power consumption at 200 watt increments, starting at 520 watts.

6.3.2.3.1.2.3.1 Concurrent to the electrical performance tests. The following additional data is required:

1. O_2 Purge solenoid (when used); voltage, current, temperature, open time and flow rate. (Make permanent recordings as specific component is used.)

2. H_2 Purge solenoid (when used); voltage, current, temperature, open time and flow rate. (Make permanent recordings as specific component is used.)

3. Pump separator drive motor and gear pump drive motor; record voltage, current, and watts.

4. Powerplant heaters; voltage, current, watts, and frequency.

5. Water condition sensor (pH); voltage output. Note: The pH sensor will not be installed in these units. Consequently, measure pH of collected water with laboratory pH meters.

6. Water; pressure and flow, lbs/hr.

7. O_2 system; pressure in, temperature in, flow rate, regulated pressure, pressure out. (Make permanent recordings during load variations.)

8. H_2 system; pressure in, temperature in, flow rate, regulated pressure, pressure out. (Make permanent recordings during load variations.)

9. N_2 System; pressure in, temperature in, regulated pressure.

10. Module surface temperature F. (Continuous permanent recordings requested with time markers.)

11. Condensor exit temperature F. (Continuous permanent recordings requested with time markers.)

12. Heat exchanger; ambient temperature, pressure in, flow in, temperature in, pressure out, temperature out. (Continuous permanent recordings requested with time markers.)

6.3.2.3.1.2.3.2 Contamination Analysis

1. Particulate (Gas and Water). Determine the particulate contamination level on a minimum of 10 ft^3 of each gas used. Perform analysis on 100 ml of powerplant water. Particle count and microscopic technique should be compatible with SAE ARP-598. Samples shall be taken at the beginning and end of the first operational test, and at the completion of each functional test thereafter.

2. Purity (Water). (Acceptance Standards to be defined by NASA). Perform analysis to determine the presence of organic and inorganic contaminants. Assay samples taken at the beginning and after each 10 hours of powerplant operation. In addition, any large or unusual particle counts are justification for additional chemical analysis.

3. Purity (Gas). Each of the pressurized gases shall be subjected to a Grade A type purity test. Any alteration of the source supply will require additional chemical analysis.

6.3.2.3.1.2.4 Voltage Versus Complete and Incomplete Venting. With the powerplant operating at 460 F surface temperature and generating 1000 watts resistive load, perform the following functions:

1. Operate until output voltage drops to 27 volts dc. At this voltage purge the H_2 and O_2 vent lines for 2.5 minutes, concurrently, recording hydrogen and oxygen line pressures, temperatures, voltage rise, purge discharge flow and purge time.

[redacted]

2. Repeat 1

3. Repeat 2, except the duration of purge shall be 1 minute.

4. Repeat 3

5. Repeat 4, except the duration of purge shall be 30 seconds.

6. Repeat 5

7. Following above tests, return unit to configuration defined in 6.3.2.3.1.2.4

6.3.2.3.1.2.5 Water Line Surge Pressure. The powerplant water discharge line is designed for 35 psia normal operating pressure. During the first 120 seconds of flight, a 57 psia pressure increase is anticipated. Consequently, with the unit operating at 1000 watts power output and a surface temperature of 460 F, apply a static water pressure of 92 psia on the discharge water line for 120 seconds. Operate the unit for a minimum of one hour thereafter, monitoring operational characteristics, to detect possible adverse effects of a surge test.

6.3.2.3.1.3 Powerplant Parallel Operation (2 Units). Functionally test unoperated powerplant for reference data and to assure similarity of operation.

6.3.2.3.1.3.1 Transient Response With Resistive Loads. With the unit surface temperatures at 460 F and the pressures as specified in 6.3.2.3.1.2.1 perform the following:

1. Increase the power output from 1000 watts to 1500 watts with the least delay possible (relay or starter). Concurrently, record voltage and current output of each powerplant and at the parallel junction. Record pressure and temperature variations.

2. After one minute, remove 500 watts and record parameters as indicated in Paragraph 1 above.

3. Repeat Paragraphs 1 and 2, except increase from 1000 watts to 2000 watts and return.

4. Increase power output to 1500 watts and stabilize.

5. Increase the power output from 1500 watts to 2000 watts with the lease delay possible, recording transient parameters listed in Paragraph 1 above.

6. Remove 500 watt load, recording transient variations.

7. Repeat Paragraphs 5 and 6, except increase from 1500 watts to 2500 watts and return.

8. Stabilize powerplants at 2000 watts.

9. Increase the power output to 2500 watts, with the least delay possible (relays, etc.), recording transient values listed in Paragraph 1 above.

10. Repeat 9, except increase from 2000 watts to 2900 watts and return, recording transient parameters.

6.3.2.3.1.3.2 Load Sharing. With the units operating at equal pressure and temperature, remove the external d-c power and feed appropriate sensors from powerplant d-c output. With a common 1100 watt resistive load, perform the following:

1. Load Sharing with Unbalanced Surface Temperature. Reduce the surface temperature in one powerplant to 440 F while increasing the surface temperature of the second unit to 480 F. Concurrently record temperatures, pressures, voltage and current from each powerplant and parallel voltage output. Operate unit for four hours at this condition, working in conjunction with Paragraph 2 below.

2. Voltage Balance Via Venting. (To be combined with Paragraph 1.) The indicated powerplant will be vented for 2.5 minutes, to balance voltage, when indicated by the following variations:

   a. A 10 F surface temperature rise in the unit operating at 480 F (vent. 440 F unit).

   b. A 10 F surface temperature drop in the unit operating at 440 F (vent. this unit).

   c. Voltage output in low temperature unit (440 F) drops to 27-volts dc (vent. this unit).

   d. Test duration is 4 hours.

3. Repeat Paragraphs 1 and 2 at 2000 watts resistive load. After 4 hours of operation balance unit temperature and voltages.

[redacted]

4. Load Sharing, Recovery Time. With the powerplants operating at equal voltages, pressures, temperatures, and at 2500 watts resistive load, perform the following:

   a. Separate the loads so that one unit is operating at 1500 watts with the second unit at 1000 watts. Operate for one hour.

   b. Parallel the loads via relay (or equivalent), recording temperatures, pressures, voltage and current of each powerplant. Continue test until units are sharing load equally.

6.3.2.3.1.4 Integrated Test With Electrical Distribution System. In portions of this test it will be necessary to have batteries capable of operating at 30 volts dc. This portion of the test will be coordinated with the Electrical Design Group which has battery responsibility.

6.3.2.3.1.4.1 Load Sharing Powerplants and Batteries. With the powerplants operating at equal temperatures (460 F), pressures, and with a 2500 watt load perform the following:

1. Increase the power output in the shortest time possible (relay, etc.) to 3600 watts, hold for one minute, reduce to 2000 watts.

2. Remove batteries from circuit for 30 seconds, then re-apply. Record temperatures, pressure, voltage, and current output of each source for tests 1 and 2.

3. Repeat Paragraphs 1 and 2 twice at 10 minute intervals. Remove batteries when test is completed.

6.3.2.3.1.4.2 Transient Response With Minimum Inductive Load. For this portion of the test, inverter availability will be required. Incorporate inverter and use as source power for 115 v, L-to-N, 400 cps, 120 watts pump drive motors.

1. The operational load on the powerplants shall be 2000 watts with provisions for the following:

   a. Inverter load approximately 1000 watts on powerplants (120 watts from pump drive motors, 184 watts from inverter at no load, 870 watts full load).

   b. 1000 watts resistive load.

   c. Provisions for removing and applying inverter resistive loads (relay, etc.).

[redacted]

2. With the units operating as rated temperatures (460 F) and pressure (Paragraph 6.3.2.3.1.2.1), apply loads A and B in Paragraph 1 above, recording data.

3. Remove inverter resistive load in the shortest time possible, recording transient variations such as pressures, temperatures, voltage, and current.

4. Apply inverter load, in the shortest time possible (relay, etc.), recording transient variations in pressures, temperature, voltage, and current.

6.3.2.3.1.5 Powerplant Operations With Hydrogen and Oxygen, Apollo Storage Tank. This phase of the test program will be coordinated with the Environmental Control Systems Group which has Apollo Dewar responsibility.

6.3.2.3.1.5.1 With a minimum of 15 foot of 1/4 in. OD stainless steel tubing, having a 0.040 inch wall thickness, connect the oxygen and hydrogen dewars to the two test powerplants and record the following:

1. Starting adjacent to the Dewar, record line temperature at three foot intervals.

2. Starting at 1100 watts output, increase wattage output by 500 watts after each hour of operation.

3. Record parameters in Paragraph 6.3.2.3.1.2.3.1.

4. After two hours operation, vent oxygen Dewar, for 3 minutes at cabin emergency flow rate, recording parameters B and C.

5. Immediately following test, remove units from area, purge with nitrogen and perform insulation resistance test as outlined in Paragraphs 4 and 5, 6.3.2.3.1.1.

6.3.2.3.2 Spacecraft. House spacecraft 1 (Boilerplate 14) a skeletal structure spacecraft, will be utilized to determine and resolve mechanical and electrical interface problems. Systems interaction, response time of regulators utilizing spacecraft plumbing, electromagnetic interference, and evaluation of design changes will be a few of the problems to be resolved.

Propulsion spacecraft (Airframe 001) is a spacecraft that will be utilized primarily for verification of propulsion systems installations and subsequent operations under static-firing conditions. Fuel cells will be tested on this vehicle to determine the ability of fuel cells to operate under

[redacted]

[redacted]

these simulated firing conditions, to provide electrical power to some of the on-board components, and to determine the ability of GSE to monitor significant fuel-cell parameters, such as temperature, pressure, water PH, etc. A secondary purpose is to evaluate methods of servicing (loading and unloading) vehicles with cryogenic reactants. The successful completion of this series of tests will permit continued testing of fuel cell modules at other facilities where the basic criteria will be operation in a vacuum chamber under simulated mission conditions.

House spacecraft (airframe 006) will contain prototype systems; thus, the over-all fuel-cell operating characteristics can be determined and evaluated. During the final phase of the program, the operating system within the spacecraft will be subjected to the dynamic environments of vibration and acoustic noise.

The fuel cell system installed in the environmental spacecraft (Airframe 008) will utilize the finalized system components—radiators, isolation valves, etc.—and will be subjected to a simulated mission while furnishing power to other spacecraft systems. The basic advantage to testing under these conditions is to evaluate problems related to heat rejection under simulated mission conditions. A 10^{-4} vacuum and simulated solar radiation source will be utilized.

6.3.2.4 Equipment

The following is an anticipated list of equipment required to conduct and support the fuel cell test effort.

Voltmeters	Vacuum gauge
Ammeters	Ground support power supply
Wattmeters	Heat sink
Recording oscillograph	Nitrogen heater
Pressure transducers	Vacuum chamber
Gas analyzer	Filters
Flow meter	Temperature transducers

6.3.2.5 Facilities

Additional test facilities will be required at S&ID for performance verification and compatibility tests of the EPS. A semi-remote building capable of handling the hazardous materials involved with the fuel cells will be provided, together with facilities for reactant storage, test stands and special instrumentation.

6.3.2.6 Test Schedules

The program schedule for the Apollo fuel cell system is shown in Figures 6-4 and 6-5.

6.3.3 Distribution Subsystem Test

6.3.3.1 Objective

S&ID tests of distribution subsystem components for boilerplates will be minimal. Qualified relays, diodes, fuses, circuit breakers, wires, and cabling will be utilized, whenever possible. Prototype subsystem components will be qualified in accordance with Apollo requirements.

In addition, effort will be expended toward accomplishment of the following objectives:

1. To standardize relays, circuit breakers, etc., where possible
2. To optimize reliability
3. To verify capacity of system and minimize losses

6.3.3.2 Test Plan

An extensive test program will be required to qualify components utilized in prototype spacecraft. Tests will be designed to establish the high order of reliability required of Apollo. Breadboards of the distribution subsystem will be utilized early in the program, and component parts will be installed in the breadboard as they are qualified. In this manner, the distribution and control portion of the EPS will have been thoroughly tested prior to prototype delivery of the subcontracted major components.

6.3.3.3 Equipment

This equipment will be provided by the S&ID Engineering Development Laboratory.

6.3.3.4 Schedule

The development schedule for the distribution subsystem is presented in Figure 6-6.

6.3.4 Illumination Subsystem Test

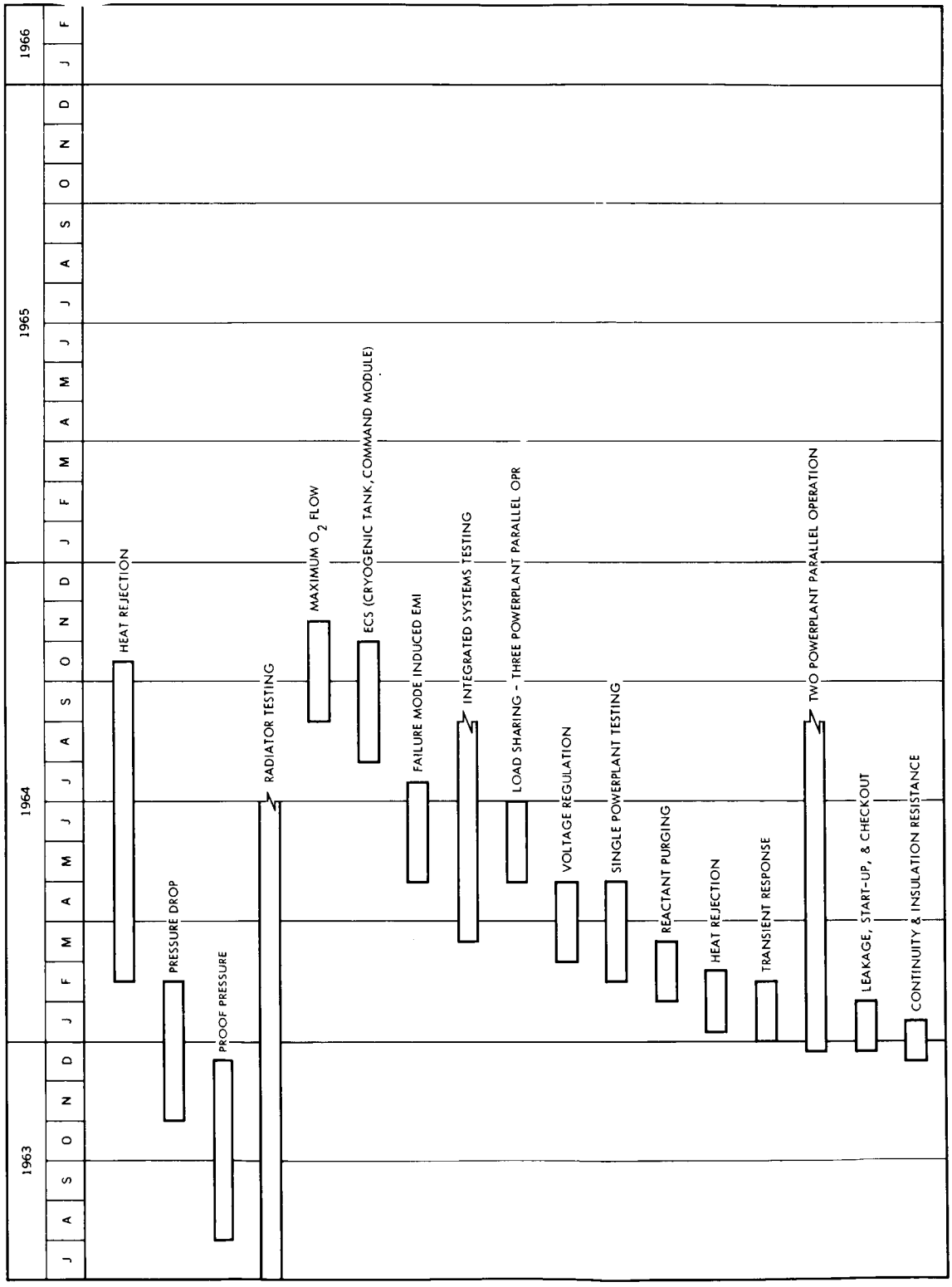


Figure 6-4. Fuel Cell Development Phasing Schedule

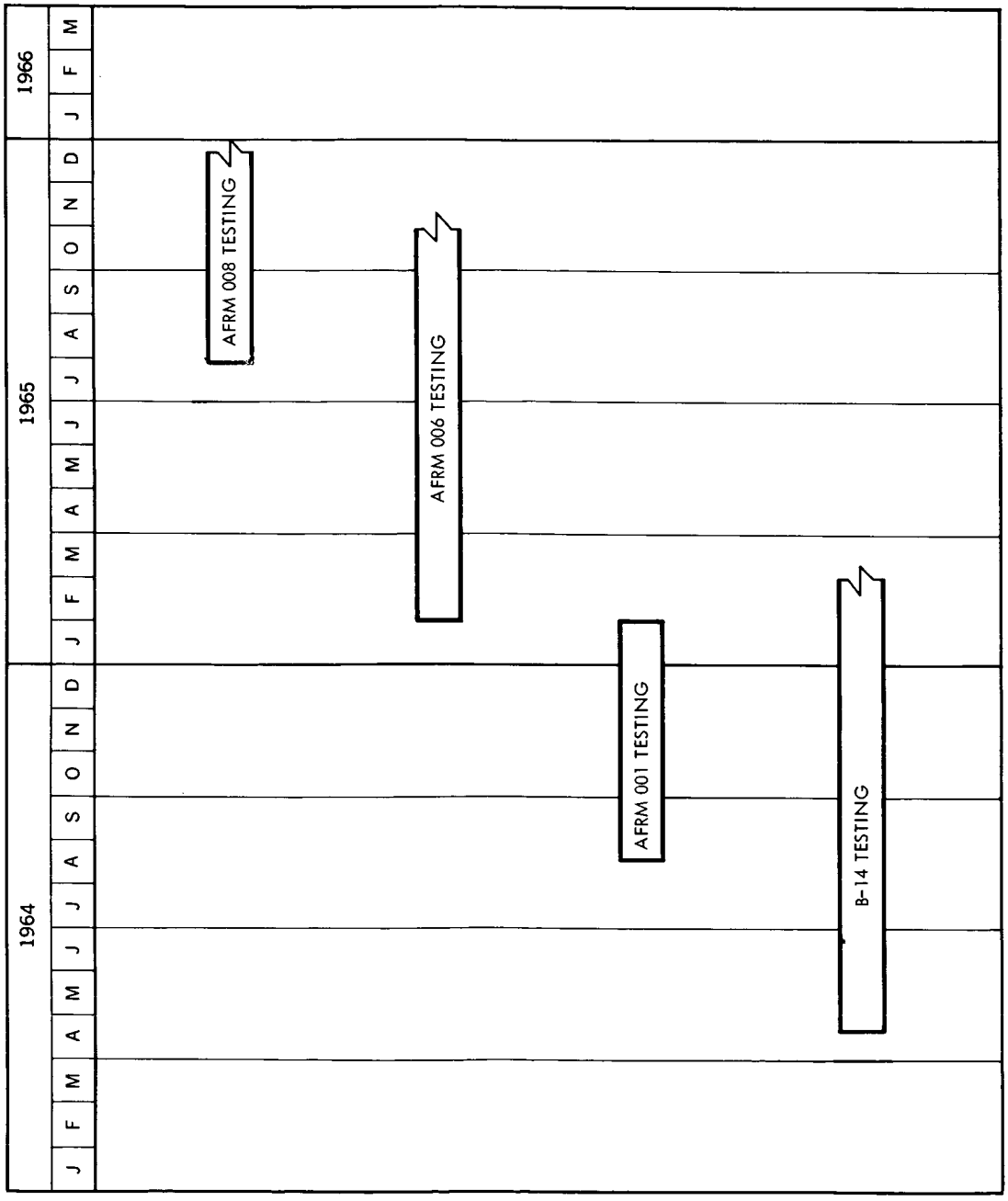


Figure 6-5. Spacecraft Fuel Cell Testing

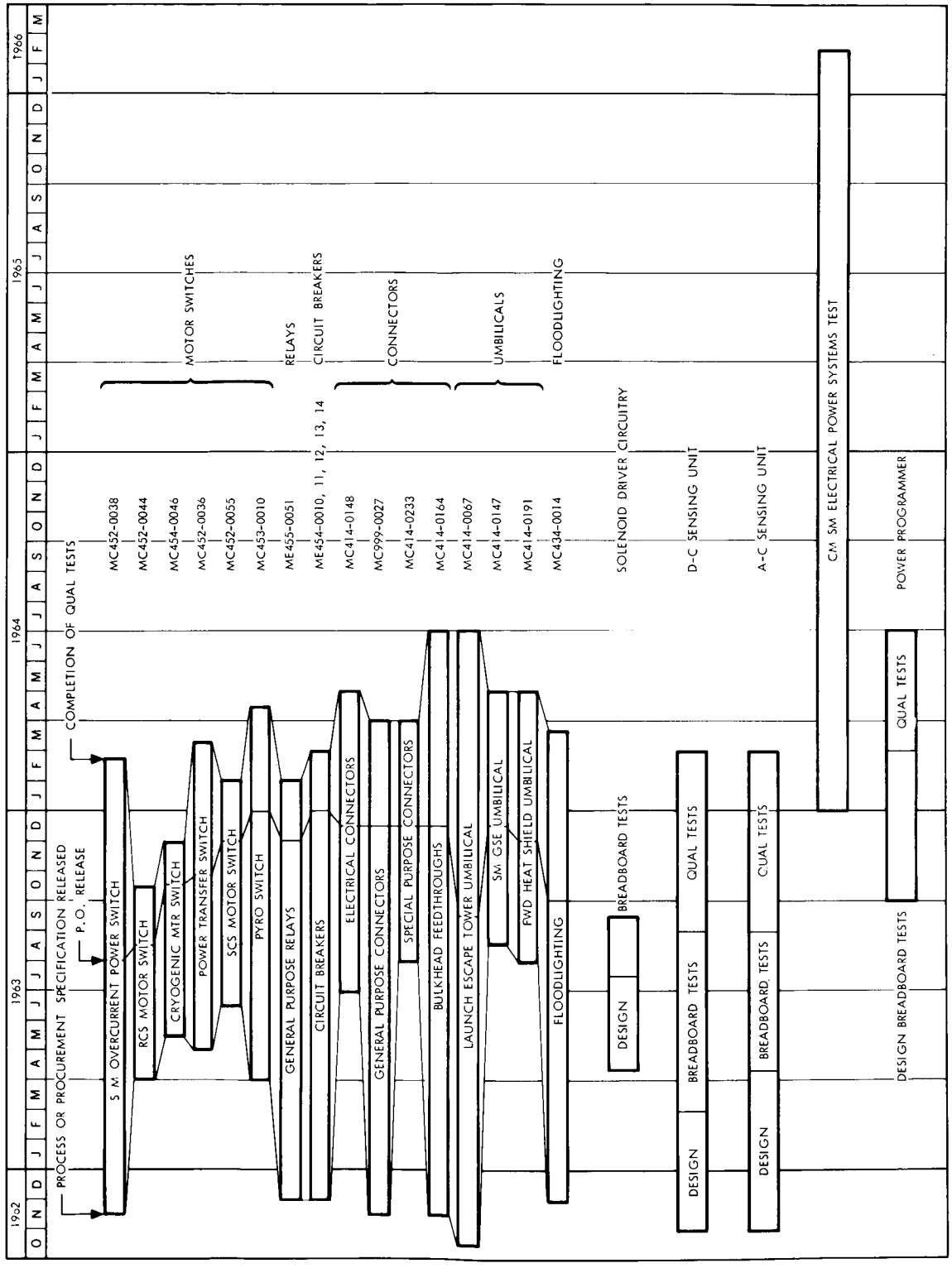


Figure 6-6. Preliminary Distribution Subsystem Development Phasing Schedule

[redacted]AL

6.3.4.1 Objective

The objective of the S&ID tests will be to provide optimum lighting for the Apollo command module with a minimum of power. Specific criteria with regard to choice of components are:

1. Efficiency
2. Power requirements
3. RFI
4. Sealing
5. Cooling

6.3.4.2 Test Plan

The test program will determine adequate lighting levels and placement of fixtures. Evaluation testing of the sealed components operating in a hard vacuum will be performed to determine service life, RFI generation, effects of cold-plate mounting, efficiency, and power factor. In addition, the lighting system will be tested for proper operation under the following conditions:

1. High temperature
2. Low temperature
3. Shock
4. Vibration
5. Acceleration
6. Humidity
7. Acoustics

6.3.4.3 Equipment

The equipment will be provided by the S&ID Engineering Development Laboratory.

[redacted]

[redacted]

6.3.4.4 Schedule

The development schedule for the illumination subsystem is presented in Figure 6-7.

6.3.5 Sequencer Subsystem Test

6.3.5.1 Objective

The development program for the sequencer subsystem will include a comprehensive development test program for approximately 4 configurations of the sequencer. The objective of this test program will be to provide a system design consistent with the high reliability and safety requirements necessary to complete a successful mission. This program will provide information during the development phase to assure acceptance during qualification testing.

6.3.5.2 Test Plan

6.3.5.2.1 Component Tests. Component parts such as relays, timers, motor switches, transistors, resistors, etc., will be subjected to various acceptance and environmental tests to verify conformance with the manufacturer's specifications and with Apollo reliability levels. Maximum qualification of all parts incorporated into circuits will be accomplished prior to callout in a design.

6.3.5.2.2 Building Block Tests. All circuit blocks, boards, or building modules used in the sequencer subsystem will be tested for conformance to specification and to a reliability level as a unit, if packaged as a unit. These modules will basically consist of solid-state switching circuits and timing circuits, logic sequencing circuits, and banks of relays. These tests will serve to assure maximum compatibility when such units are assembled into a sequencer subsystem for a particular configuration.

6.3.5.2.3 Subsystem Tests. Each sequencer subsystem for a particular circuit configuration will be mechanized by constructing an experimental breadboard circuit as early as feasible during the design phase. Some vehicular configurations will be basically similar in nature and therefore modifications will be made to the basic sequencer breadboard to accomplish the next boilerplate or AFRM mission. Thus an approximate total of four sequencer breadboards will be constructed. Operational tests will be conducted on the breadboard model to demonstrate the workability of the design of the system, and a bilateral development improvement program will be conducted between breadboard and design functions.

[redacted]

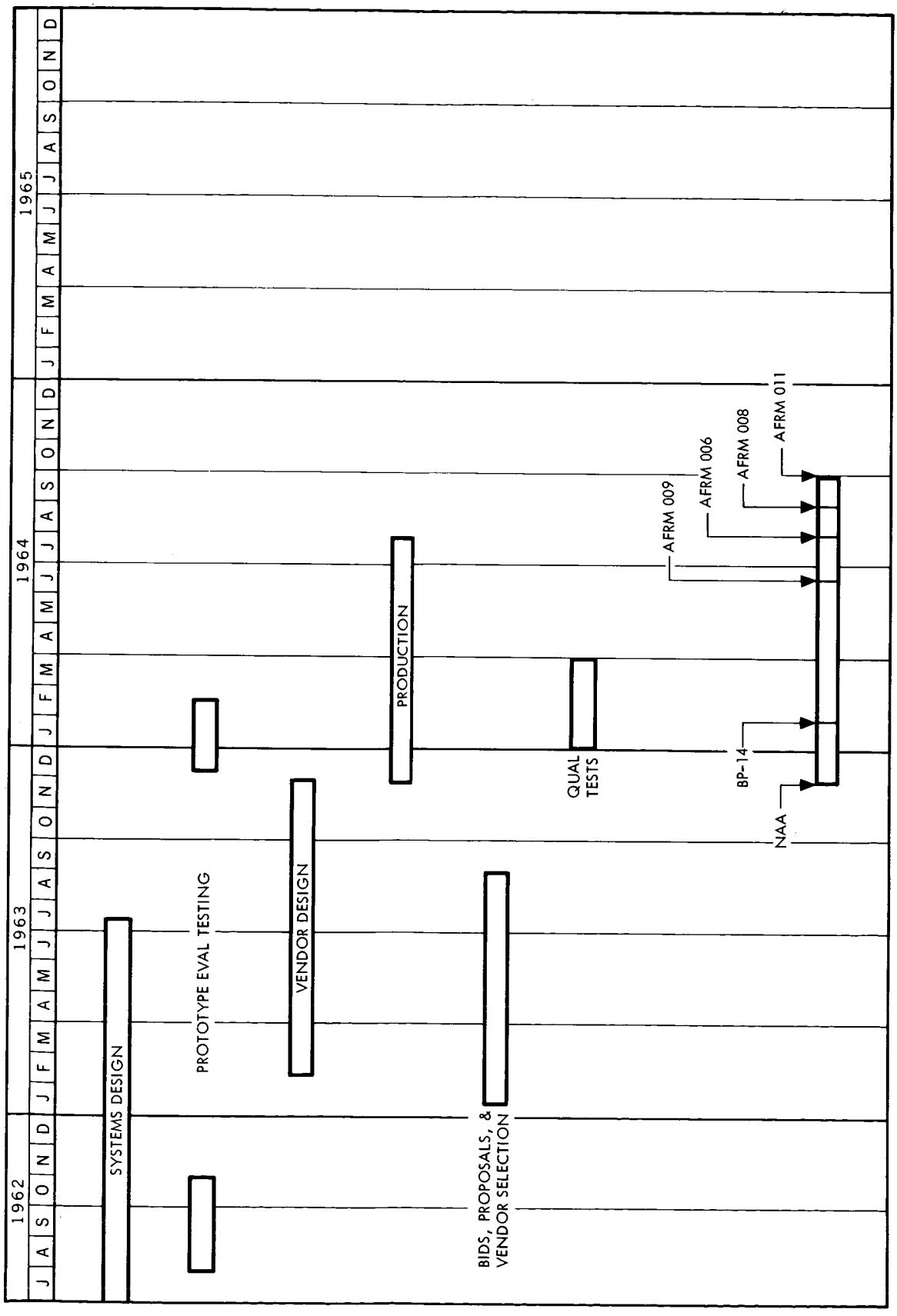


Figure 6-7. Preliminary Illumination Subsystem Development Phasing Schedule

[redacted]

6.3.5.2.4 Environmental Tests. A total of 10 packaged sequencer units will be constructed. Six of these will be in the boilerplate configuration and the remaining four will be in the spacecraft configuration. The six boilerplate units will be manufactured in lots of two to assure maximum similarity between units.

The sequencer units will be subjected to all environments which might exist for a mission typical for the vehicle configuration. If failures are experienced in the test program, the entire lot will be reworked to correct the malfunction, and the tests will be repeated.

6.3.5.3 Equipment

6.3.5.3.1 Component Tests. Complete electronic laboratory test facilities will be required to test component parts in the sequencer subsystem.

6.3.5.3.2 Building Block Tests. Testing facilities will be necessary to perform electrical tests on building blocks to determine switching time, transient response, noise susceptibility, etc. Complete environmental test facilities also will be required.

6.3.5.3.3 Subsystem Tests. Facilities for constructing, modifying, and testing breadboard circuits will be provided. Equipment provided must be capable of assessing over-all subsystems performance and performance of the subsystem when coupled with interfaces of simulated tie-in systems.

6.3.5.3.4 Environmental Tests. Complete environmental test facilities are necessary to test the subsystem in environments to be encountered in any Apollo mission.

6.3.5.4 Schedule

The development schedule for the sequencer subsystem is presented in Figure 6-8.

6.3.6 Pyrotechnic Subsystem Test

6.3.6.1 Objective

The objective of S&ID tests will be to assure compatibility between the hot-wire initiator and the various cartridges which the initiator ignites, including pressure cartridges, explosive bolts, and detonators for linear shaped charges.

[redacted]

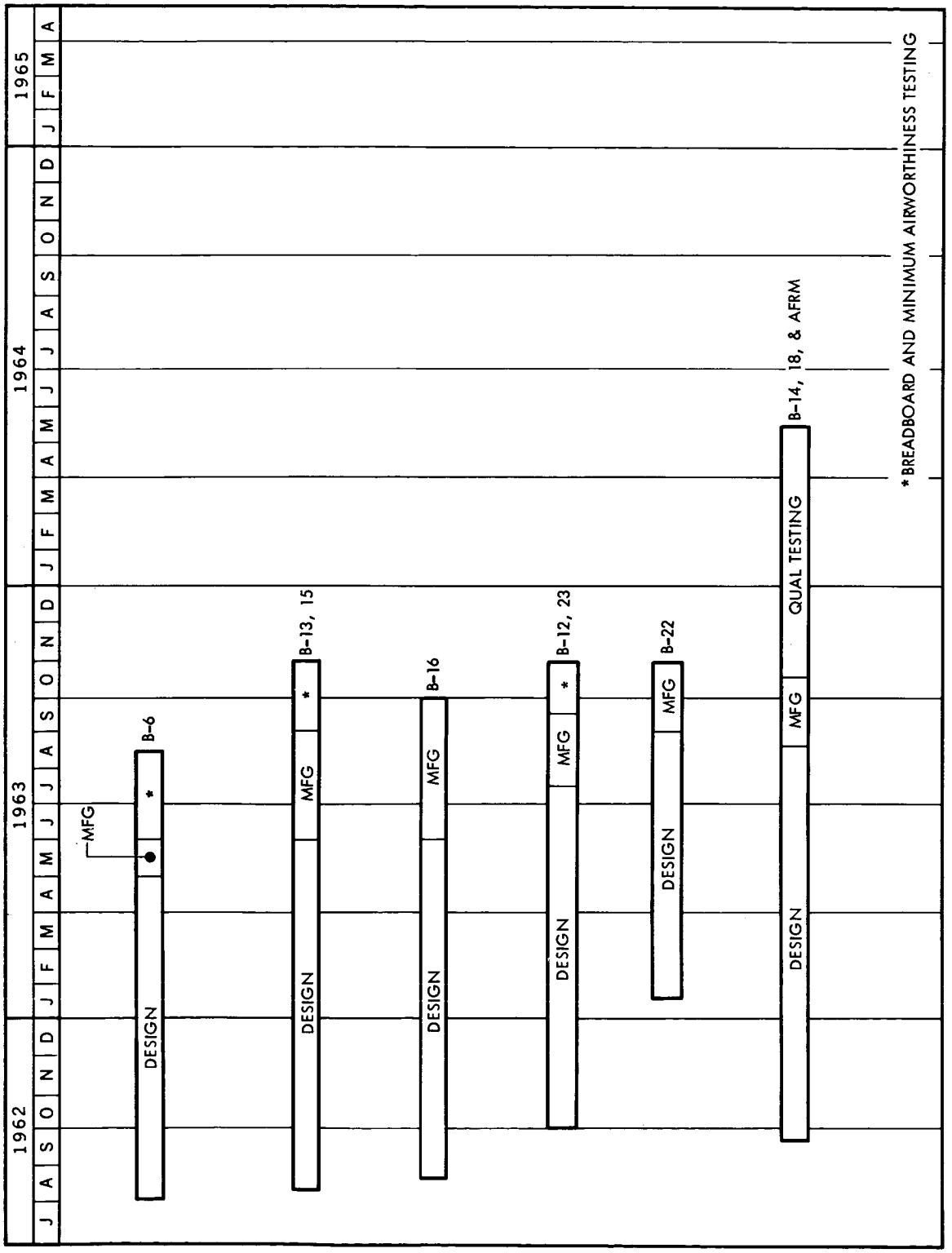


Figure 6-8. Preliminary Apollo Sequencer Development Phasing Schedule

[redacted]

6.3.6.2 Test Program

The pyrotechnic subsystem is composed of the following components:

1. Hot-wire initiator for initiation or actuation of:
   a. 36 explosive bolts (72 Initiators-36 Detonators)
   b. 116 linear shaped charges for separation of structures and wiring cables
   c. Gas generator thrusters for separation (78 Cartridges-6 Initiators)
   d. Mortars for parachute deployment (210 Cartridges and Initiators)
   e. Release mechanisms for chutes (72 Initiators and Shaped Charges)
   f. Squib valves for RCS pressurization (150 Initiators)
   g. Explosive switches for dead facing electrical wiring. (150 Initiators)
2. Solid rocket motor EBW initiators (squibs) (boilerplate 6 only), launch escape system (250 Igniter Cartridges)
3. EBW firing units for rocket motor ignition

The test program will verify operation of the hot-wire initiators to be used in the major components and EBW firing units to be used in the launch escape system. The hot-wire initiators and EBW firing units and components will be tested on an individual basis. System compatibility tests of the electrical system and the pyrotechnic system utilizing initiator simulators will be accomplished during house spacecraft tests and during checkout of boilerplates 6 and 8. Hot wire igniters will replace EBW on all uses after boilerplate 6.

6.3.6.3 Development Schedule

The development schedule for the pyrotechnic subsystem is presented in Figure 6-9.

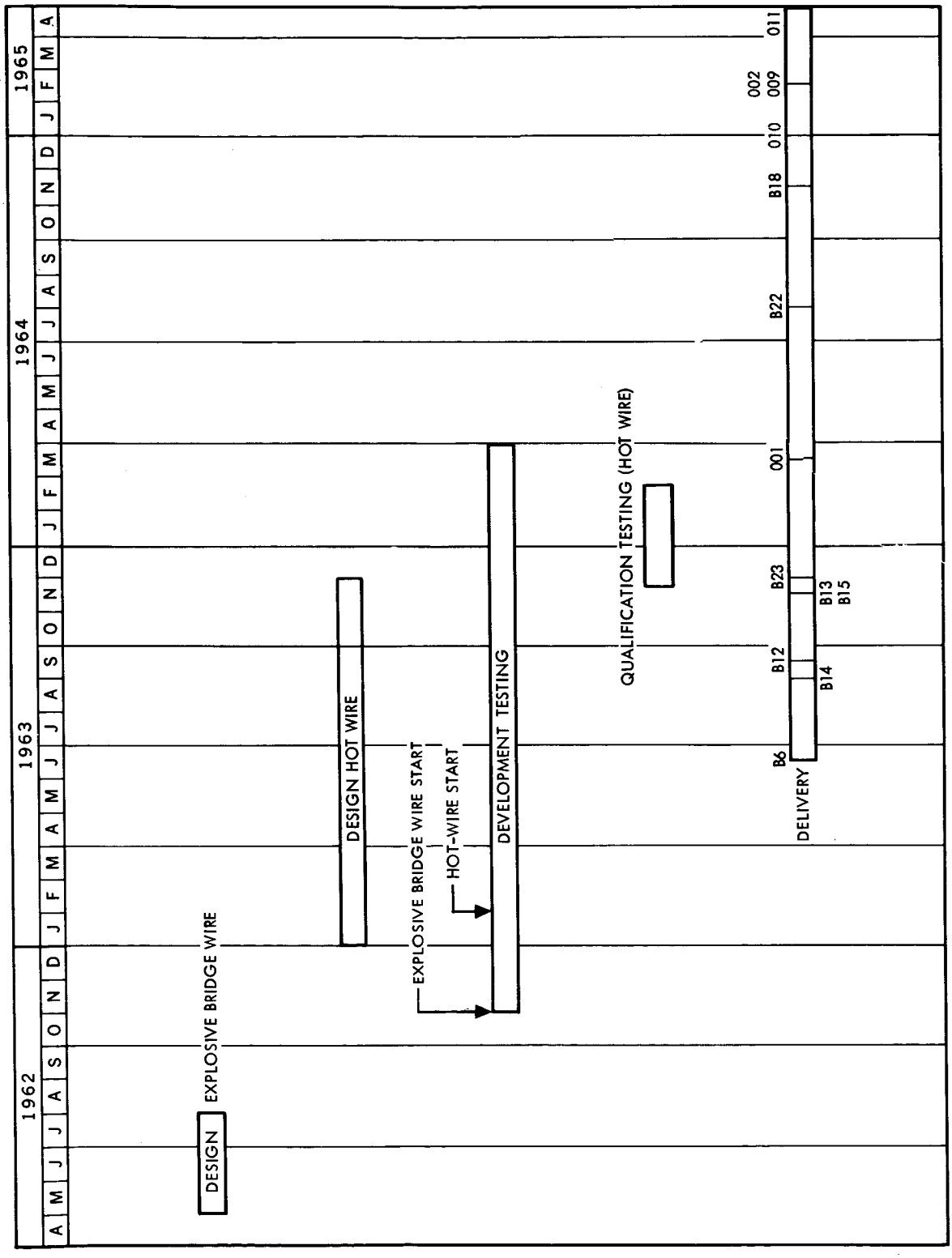


Figure 6-9. Apollo Pyrotechnics Development Phasing Schedule

[redacted]

6.3.7 A-C and D-C Voltage Sensing Units

6.3.7.1 Objective

S&ID development personnel will design and qualify two breadboard voltage sensing units, one for monitoring d-c voltage and one for monitoring a-c voltage. The breadboard approach will enable S&ID to determine early in the program if the designs are sound and also to design and evaluate proposed circuit variations. The Engineering Development Laboratories at S&ID, Downey, California, will perform both the breadboard tests and qualification tests of final hardware. In addition, the electrical power systems compatibility tests will evaluate the performance of the operational components. Some specific objectives of the electrical power systems tests are as follows:

1. To determine the response of both a-c and d-c sensing units to steady-state voltage levels within the intended tolerances of spacecraft power sources.

2. To determine the response of both a-c and d-c sensing units to steady-state voltages below the tolerances of spacecraft power sources.

3. To determine the response of both a-c and d-c sensing units to short term over and under voltage transients superimposed on normal spacecraft power source voltage levels.

4. To determine the response of the a-c sensing unit to steady-state voltage levels above the tolerances of the spacecraft a-c sources.

5. To determine the ability of both a-c and d-c sensing units to be reset to their normal mode after having been driven to their respective alarm modes by an out of tolerance condition.

6. To determine the ability of both the a-c and d-c sensing units to function correctly while operating in environments of temperature excursions above and below those anticipated in actual operation.

7. To determine the response of the a-c sensing unit to an overload signal from the inverters.

6.3.7.2 Test Plan

Breadboards of the a-c over and under voltage sensing unit and the d-c under voltage sensing unit will be used early in the program. Component parts will be installed in the breadboards as they are qualified.

System compatibility tests utilizing prototype units manufactured by S&ID will prove the design and packaging in its spacecraft configuration.

6.3.7.3 Equipment and Facilities Required

The equipment and facilities required will be provided by S&ID Engineering Development Laboratory.

6.3.7.4 Development Schedules

The development test schedules for the a-c and d-c sensing units are presented in Figure 6-5.

6.3.8 Unmanned Spacecraft Power Programmer

6.3.8.1 Objective

S&ID development personnel will design, fabricate and qualify a breadboard power programmer, adaptable to all anticipated unmanned spacecraft missions. Primary functions of the programmer will be to accomplish the power switching normally done by an astronaut, both in normal and in emergency modes of operation. The breadboard approach will enable S&ID to determine early in the program if the designs are sound and also to design and evaluate proposed circuit variations as a function of mission profile. The Engineering Development Laboratories at S&ID, Downey, California, will perform both the breadboard tests and qualification tests of final hardware. In addition, the electrical power systems compatibility tests will also evaluate the performance of the operational components. Some specific objectives of the electrical power systems tests are as follows:

1. To determine the response of the programmer to a d-c low voltage alarm situation.

2. To determine the response of the programmer to an a-c low voltage alarm situation.

3. To determine the response of the programmer to an a-c overvoltage alarm situation.

4. To determine the ability of the programmer to disconnect a failed inverter from its input and output mains, connect a spare inverter to the appropriate mains and sequentially start all of the a-c loads involved.

5. To determine the capability of the programmer to shut-off fuel cell fuel supplies and disconnect fuel cell electrical loads either in an emergency situation or just prior to C/M - S/M separation.

6. To determine the capability of the power programmer to parallel the battery combinations during the post-landing period to make maximum use of remaining power capability.

7. To determine that maximum switching capability and versatility are combined with minimum power consumption within the power programmer.

8. To determine that the programmer will function correctly in spite of the supply voltage variations possible during a malfunction.

6.3.8.2 Test Plan

A breadboard of a power programmer suitable for a specific unmanned mission will be designed and fabricated early in the program. Component parts will be installed in the breadboard as they are qualified. System compatibility tests utilizing inverters, batteries, chargers, fuel cells, umbilicals and the complete distribution system will provide short-circuit data, overload characteristics, and over-under voltage performance. Prior to house spacecraft tests, electromagnetic interference will be minimized through preliminary analysis and system compatibility tests.

6.3.8.3 Equipment and Facilities Required

The equipment and facilities will be provided by S&ID Engineering Development Laboratory.

6.3.8.4 Development Schedules

The development test schedules for the unmanned spacecraft Power Programmer is presented in Figure 6-5.

[redacted]

7.0 GUIDANCE AND NAVIGATION SYSTEM

7.1 SCOPE

Efforts concerning the development, design verification, evaluation, qualification, and reliability testing of the guidance and navigation subsystems, and systems are specifically divided between the associate contractor and S&ID. The test programs conducted by the associate contractor and S&ID will be integrated to avoid redundancy and to provide maximum confidence level in the success of the end requirement, lunar orbit and return.

7.2 ASSOCIATE CONTRACTOR TEST PLAN

The Massachusetts Institute of Technology (MIT) test plan is negotiated between MIT and NASA. Consequently, it is not a part of this test plan.

7.3 S&ID TEST PLAN

7.3.1 Objectives

The S&ID test plan is being completely rewritten and will be included in the 31 March 1964 revision.

[redacted]

[redacted]

8.0 STABILIZATION AND CONTROL SYSTEM

8.1 SCOPE

Development, design verification, evaluation, prequalification, and, acceptance testing of the stabilization and control components, subsystems, and systems will be done jointly by the subcontractor and prime contractor. Only the engineering development, evaluation, and design verification tests are outlined herein. Qualification test plans will be reported in Volume III.

8.2 SUBCONTRACTOR TEST PLAN (MINNEAPOLIS-HONEYWELL)

8.2.1 Objectives

The stabilization and control test plan includes the development and design verification testing of the prototype SCS.

The test plan is designed to allow a smooth transition between the various development stages. Over-all end requirements (lunar orbit and return) will be met on the hardware intended for the final phase by progressively increasing the severity of the environments.

8.2.2 Test Plan

The types of tests to be conducted on the prototype SCS include circuit development, component development, system development, system breadboard, computer simulation, radio interference environmental evaluation, design improvement, and acceptance tests.

8.2.2.1 Prototype Stabilization and Control System

The prototype SCS consists of the following subsystems:

1. Attitude gyro, accelerometer package (AGAP)
2. Pitch channel electronic control assembly (pitch ECA)
3. Roll channel electronic control assembly (roll ECA)
4. Yaw channel electronic control assembly (yaw ECA)
5. Auxiliary electronic control assembly (auxiliary ECA)
6. Display electronic control assembly (DECA)
7. Translation control
8. Three-axis rotation control
9. V display

[redacted]

10. Attitude set-gimbal position display
11. SCS control panel
12. Flight director attitude indicator (FDAI)
13. Rate gyro package (RGP)

One engineering functional breadboard model of each subsystem will start development testing. Four subcontractor in-house prototype SCS will be used for prequalification and design-improvement testing.

8.2.2.2 Circuit Development Tests

These tests are normally carried out during the early stages of any design and development program. Initial analysis and system studies are converted to breadboard hardware and tested for verification of device or system concepts. These tests are performed primarily to reduce errors and rework in subsequent component and subcomponent development. The prototype SCS will require new hardware as well as new circuitry principles, and an extensive development program is expected. Minuteman parts will be used as available to meet schedules. Additional functions to be performed, particularly involving the human interface, demand that multiple functions for circuitry be used to the fullest extent. Transfer function open-loop and closed-loop tests with simulated or actual controls will be performed.

Integration of IFTS and PACE-S/C, particularly for normalization of signals, will be tested at the earliest possible time. Some detail areas of circuit development testing will include pulsing logic, jet switch logic, special filters, sensor tuning, and synchronizer circuits.

8.2.2.3 Component Development Tests

An extensive program is planned in this area, aimed at determining all important operation parameters of all components within subsystem packages. Subcomponents, such as amplifiers and logic, will be tested as developed, using parts needed to attain ultimate reliability.

A great deal of testing is anticipated even in components (such as amplifiers) that are modified slightly from an electronic standpoint. An additional area of component development testing will involve certain environmental requirements. Many of the conditions to be met by the system will require preliminary testing prior to full-fledged environmental tests, to reduce lead-time and obtain data at the earliest possible time.

The gyros supplied by the subcontractor are of types used in quantity on current missile and space programs. In addition, extensive environmental and life tests have been conducted on the component, subassembly, and complete gyro assembly levels in support of the Apollo Program.

Solid-state switching has been used to the greatest extent possible to the point where space restrictions and reliability considerations necessitated use of relays. For general application, relays with adequate historical and qualification test data were selected. Where microminiature types are required, rigid specification control has resulted in a program consisting of subcontractor vendor selection testing and subsequent qualification testing by both the relay vendor and system subcontractor.

A major program of packaging will be concurrently in progress with the preceding work. Many of the environmental factors, such as heat dissipation at drastically reduced pressures, must be evaluated in conjunction with packaging techniques.

8.2.2.4 System Development Tests

Tests will be conducted throughout design and development phases to show that a crew can perform with a high level of proficiency while using the subcontractor's equipment. Major areas to be verified by testing are as follows:

1. Suitability of displays and controls for the planned mission
2. Procedures and equipment for maintenance
3. Compliance of designed equipment with requirements established in preliminary design
4. Suitability of suggested operating procedures for individual spacecraft systems and for ground support equipment

Human factors testing will be reported in writing and documented by still and motion pictures. Experimental design to ensure statistical reliability of results will be preplanned. This testing will consist of satisfying system performance requirements and in obtaining satisfactory pilot opinion ratings by means of simulation shown in Figures 8-1 and 8-2.

8.2.2.5 Computer Simulation Tests

This phase will consist of dynamic closed-loop testing of both manual and automatic control modes, using analog computers to simulate reaction controls and vehicle dynamics. Both actual and simulated output dynamics will be used. Tests will be conducted to determine dynamic system stability, operation of system displays, and effects of voltage and frequency variations on system stability. This phase will include dynamic closed-loop tests on the air-bearing table, using actual sensors, displays, and simulated output devices.

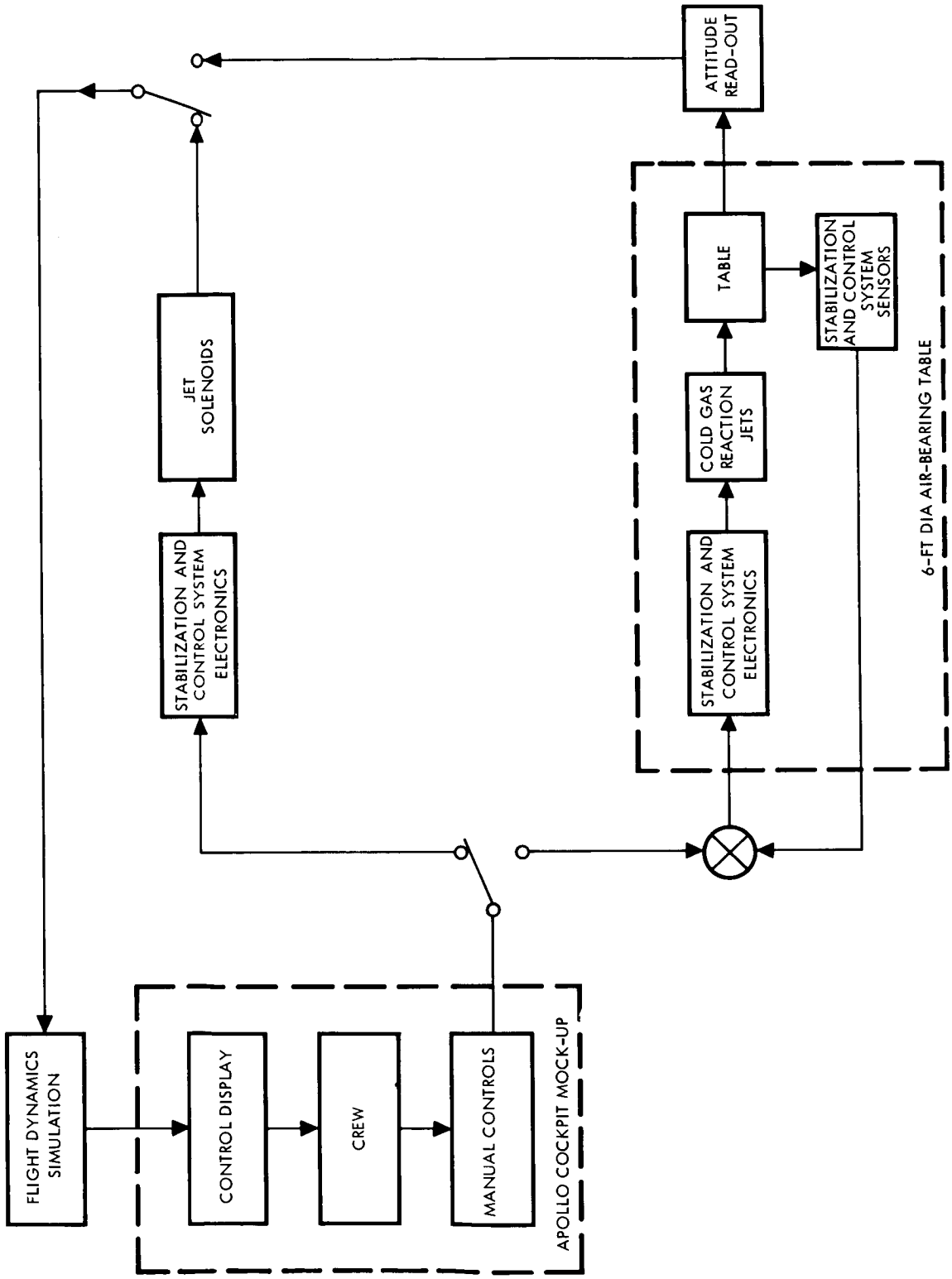


Figure 8-1. Apollo Augmented Continuous Control Evaluator

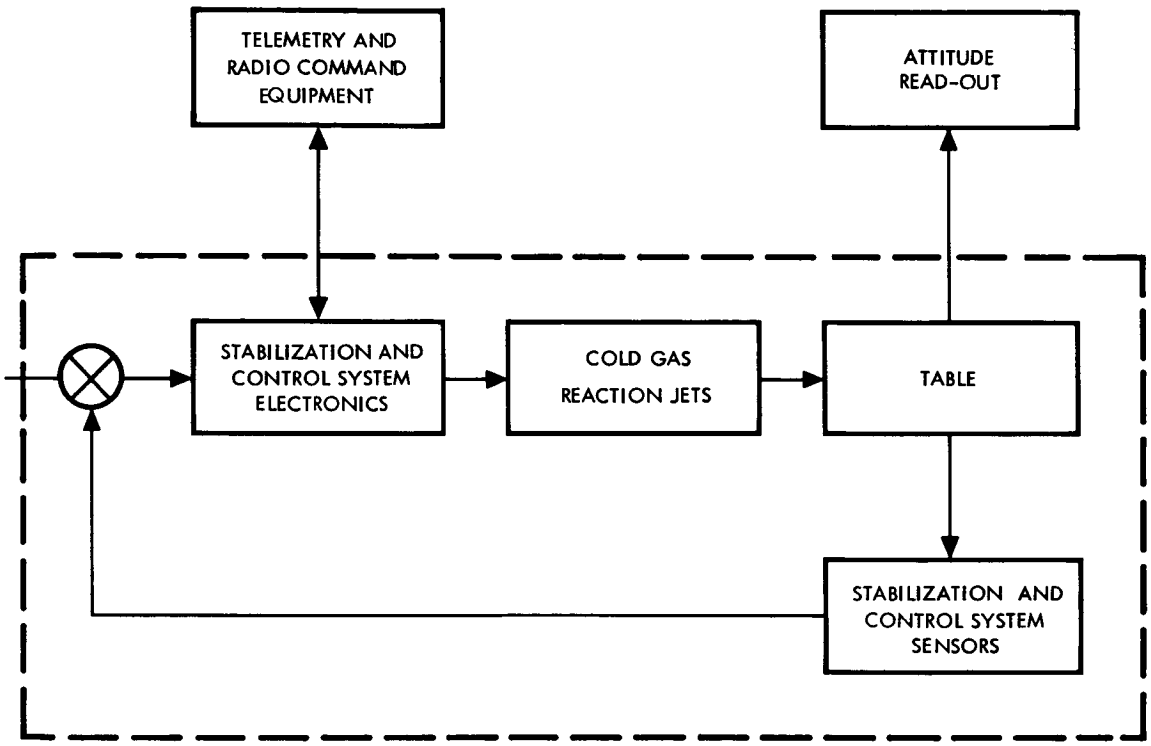


Figure 8-2. Apollo Dynamic Attitude Control Simulator

[redacted]

8.2.2.6 System Breadboard Tests

This phase will consist of the static tests listed under the following two categories:

1. Simulated sensors, controls, instruments, and displays

   a. Final verification of all inter-component and interface cabling

   b. Verification of compatibility between GSE and SCS

   c. Quantitative performance tests to verify preliminary specifications for manual control modes and to establish final performance specifications

   d. Quantitative performance tests to verify final performance specification for automatic control modes

2. Actual sensors, controls, instruments, and displays

   a. Functional phasing checks

   b. Verification of system compatibility and display operation

   c. Effects of voltage and frequency variations on system operation

   d. System power consumption measurements

8.2.2.7 Radio Interference Tests

Radio interference tests will be conducted on the completed subsystems, and will be based on familiarization studies of the system, predictions of interference areas, and problems encountered during design and development phases. Additional filtering and/or repackaging will be completed prior to system testing, and based upon results of the preceding testing. Radio interference tests will be conducted at the system level, and additional filtering and repackaging incorporated where required.

8.2.2.8 Environmental Tests

Testing will be done on basic materials, components, subsystems, and under environmental limits throughout the entire program, with the end results compatible with lunar mission and return requirements. Subsystem testing will be conducted in two phases.

[redacted]

1. Prequalification tests will assure subsystem and system capability to operate satisfactorily under maximum environmental extremes expected during the mission.

2. Stress testing by means of increasing the environmental stress level will determine the safety margin of the components.

8.2.2.9 Design Improvement Tests

The design program on the prototype SCS will involve a continual upgrading of performance and reliability characteristics of the whole system. As data accumulates from all other test results (including subcontractor and NAA testing during prequalification, acceptance, prelaunch, and flight tests) new designs must be evaluated for over-all system improvement. Additionally, state-of-the-art developments independent of this program must be incorporated into the system, particularly in areas that may be marginal from a performance, reliability-maintainability, or producibility standpoint.

Independently, specific design effort and test evaluation will be continued toward simplification, parts evaluation, and size reduction in areas where time would not permit in the original design effort.

8.2.2.10 Acceptance Test

The following tests (as applicable) will be conducted to assure product acceptability.

1. Product examination

2. Dielectric strength

3. Insulation resistance

4. Performance (room temperature only)

Subsequent systems:

1. Examination of product

2. Leakage

3. Dielectric strength

4. Performance

[redacted]

5. High temperature - operating

6. Low temperature - operating

7. Altitude

8. Acoustic noise

9. Vibration

The minimum acceptance-test operating time is 100 hours. (Minimum operational time is defined as system operating time not including prior operating time accrued by individual components. The last ten hours of system operation must be failure-free.)

8.2.3 Equipment

1. Shock tester

2. Vibration shock, acceleration holding fixture

3. RF noise generators (to 5.4 kmc)

4. C-25 vibration machine

5. C-125 vibration machine

6. Air-bearing table (6 feet diameter, 400 slug-feet^2)

7. Miscellaneous test instrumentation

8. GSE

9. Air-bearing table (13 feet diameter, 25,000 slug-feet^2)

8.2.4 Facilities

1. High-low temperature chamber

2. Altitude temperature chamber (10^6 mm Mg)

3. Radio screen room

4. Explosion-proof chamber (100 percent O_2 at 5 psia)

5. Acoustic noise chamber

6. Environmental test chamber

8.2.5 Test Schedule

For the test schedule refer to Figure 8-6 at the end of this section.

8.3 S&ID TEST PLAN

8.3.1 Objective

Prime contractor's tests will augment the subcontractor's test program with design verification and evaluation testing that will explore the complete S&C system and combined systems problems. Emphasis will be on all major interface areas encountered in the spacecraft.

8.3.2 Test Plan

The types of tests to be conducted on the prototype SCS include subsystem evaluation, subsystem interface evaluation, system evaluation, and analog/hardware simulation tests. The test setups, techniques, and general approach will be different from those used by the subcontractor, so that these tests can serve as an effective verification of the subcontractor's test results.

8.3.2.1 Subsystem Evaluation Tests

These tests will be performed on all major elements of the stabilization and control systems in the prime contractor's engineering laboratories. Inertial devices will be tested to determine transfer functions, linearity, scaling, resolution, deadband, torquing accuracies, null shift characteristics, etc. Semiconductor modules such as signal amplifiers, power amplifiers, demodulators, etc., will be thoroughly tested to determine gain characteristics, nonlinearities, effects of noise, effects of power supply variations, etc. Power supplies will be tested to determine regulation characteristics, output wave form characteristics, effects of variations of source power, and possible malfunction modes and their effects on over-all system operation.

8.3.2.2 Subsystem Interface Evaluation Tests

Subsystems, such as engine gimbal servo loops and reaction-control logic, will be tested in conjunction with their interface systems or system components to determine and verify compatibility, effects of in-design and off-design tolerance excursions, combined systems transfer

functions, deadbands, nonlinearities, etc. Reaction-control logic schemes will be breadboarded and compared in a single degree of freedom sense for tradeoffs in energy management, deadband size, minimum realizable vehicle rates, etc., in conjunction with an analog computer. Engine-gimbal servo loops will be tested statically and dynamically with various loads applied and under actual firing conditions at the WSMR.

8.3.2.3 System Evaluation Tests

Complete prototype SCS will be tested in the engineering laboratories to determine, verify, and evaluate system parameters and characteristics, compatibility with interface systems and GSE, interchangeability, effectiveness of checkout procedures, malfunction mode analysis, error analysis verification, effects of variations of power systems, and compatibility with the manual controls and displays.

8.3.2.4 Analog/Hardware Simulation Tests

Comprehensive evaluation testing of the stabilization and control system, using the analog computer to close the outer loop around the portion of the system being tested, will be conducted as breadboard and prototype hardware become available. This portion of the test program will investigate the effects, hardware nonlinearities, associated variations on margins of stability and limit-cycle characteristics for various flight modes, and investigate system interaction and effectiveness when undergoing simulated flight conditions.

Because of the lead times involved in procuring engine system components, flight tables, etc., the analog/hardware simulation tests will be divided into phases.

Phase I will consist of pure synthesis of control problems in which stability and control system hardware as well as vehicle parameters will be simulated on the analog or digital computer. During these studies, stabilization and control hardware characteristics will be represented as accurately as known within the capability of normal programming. The results of these studies will be the basis of the functional system design and hardware development and fabrication.

Control electronics hardware will be tested in conjunction with the analog computer. In these early simulations, vehicle dynamics, sensor dynamics, valve and engine dynamics, gimbal actuator dynamics will be simulated on the computer, and only the control electronics will be used to complete the loop outside the computer.

Phase II tests will serve as a means of determining and evaluating the effects of the hardware characteristics of the control electronics

portions of the system. All flight modes will be studies and new computer programs will be written to include mechanization of those nonlinearities, discontinuities, etc., determined to be significant.

A block diagram of the Phase II test configuration is shown in Figure 8-3.

Phase III will be similar in intent to Phase II simulation tests, except that reaction-control engines and engine-gimbal actuators will be added to the hardware in the loop outside the computer.

Load simulators will be utilized, if required, to load engine-gimbal actuators, and engine geometric center-line position (representative of thrust-vector position) will be instrumented if engine-actuator-structure compliance is determined to be a problem.

A block diagram of the Phase III test configuration is shown in Figure 8-4.

The intent of Phase IV will be similar to that of Phases II and III, except that angular inertial elements will be placed on a flight table driven by vehicle angular rates as determined by the computer.

A block diagram of the Phase IV test configuration is shown in Figure 8-5.

8.3.3 Equipment

Dividing head (Leitz)

Rate table (Genisco C-181)

Flight table (to be determined)

GSE

Miscellaneous instrumentation

8.3.4 Facilities

The guidance and control system laboratory and the analog-digital computer will be used.

8.3.5 Schedule

A schedule of R & D test activity is shown in Figure 8-6.

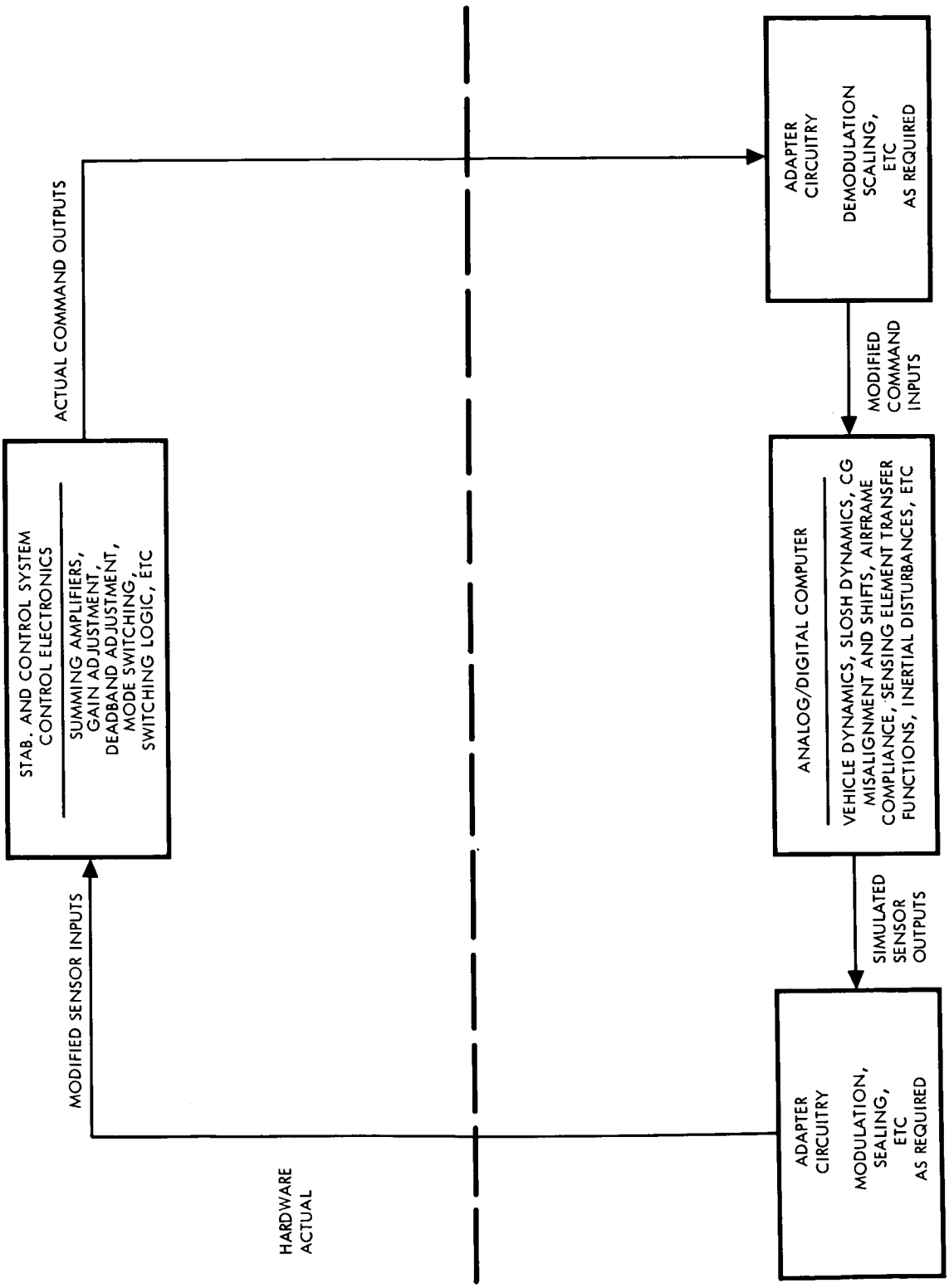


Figure 8-3. Phase II Test Configuration

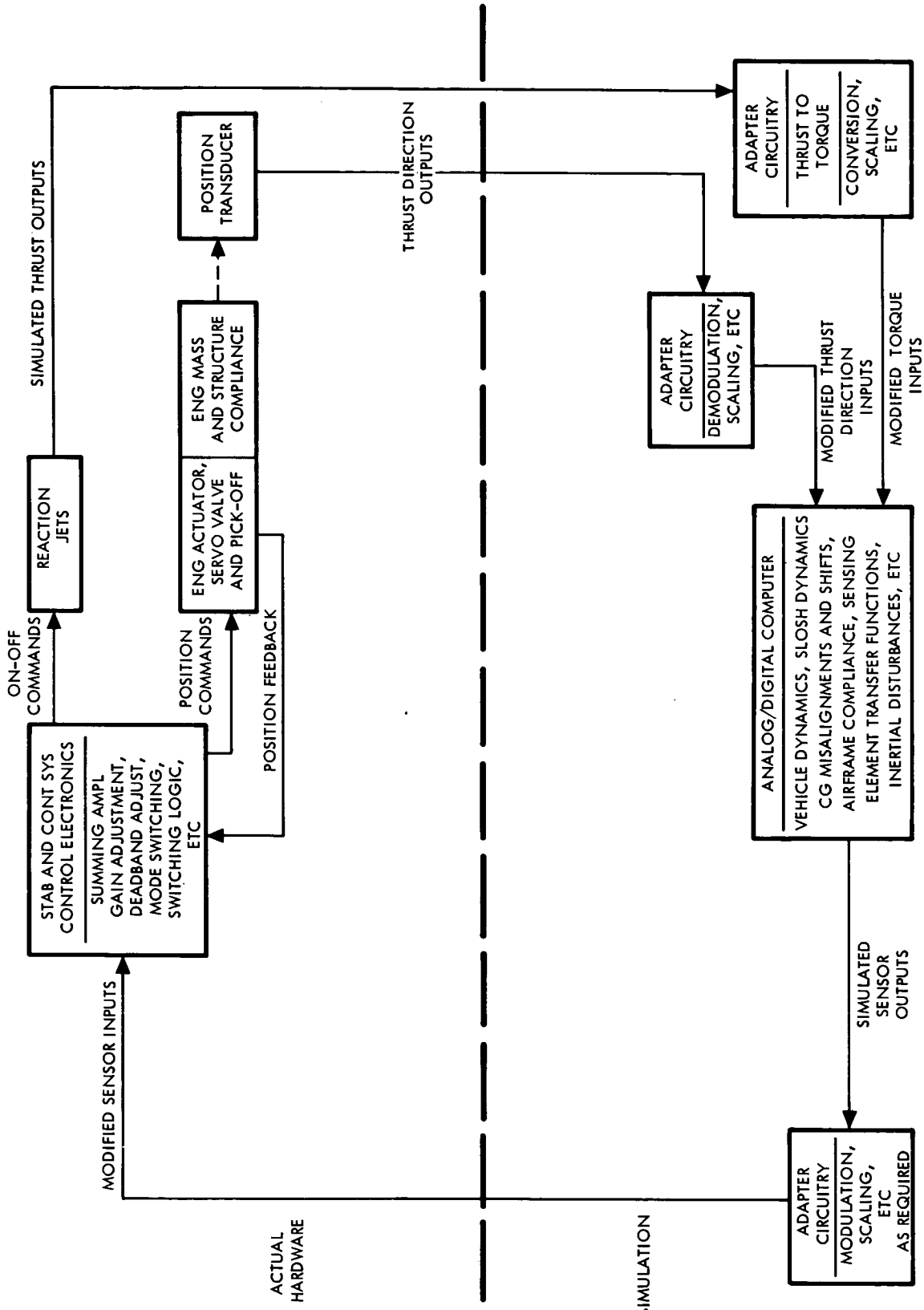


Figure 8-4. Phase III Test Configuration

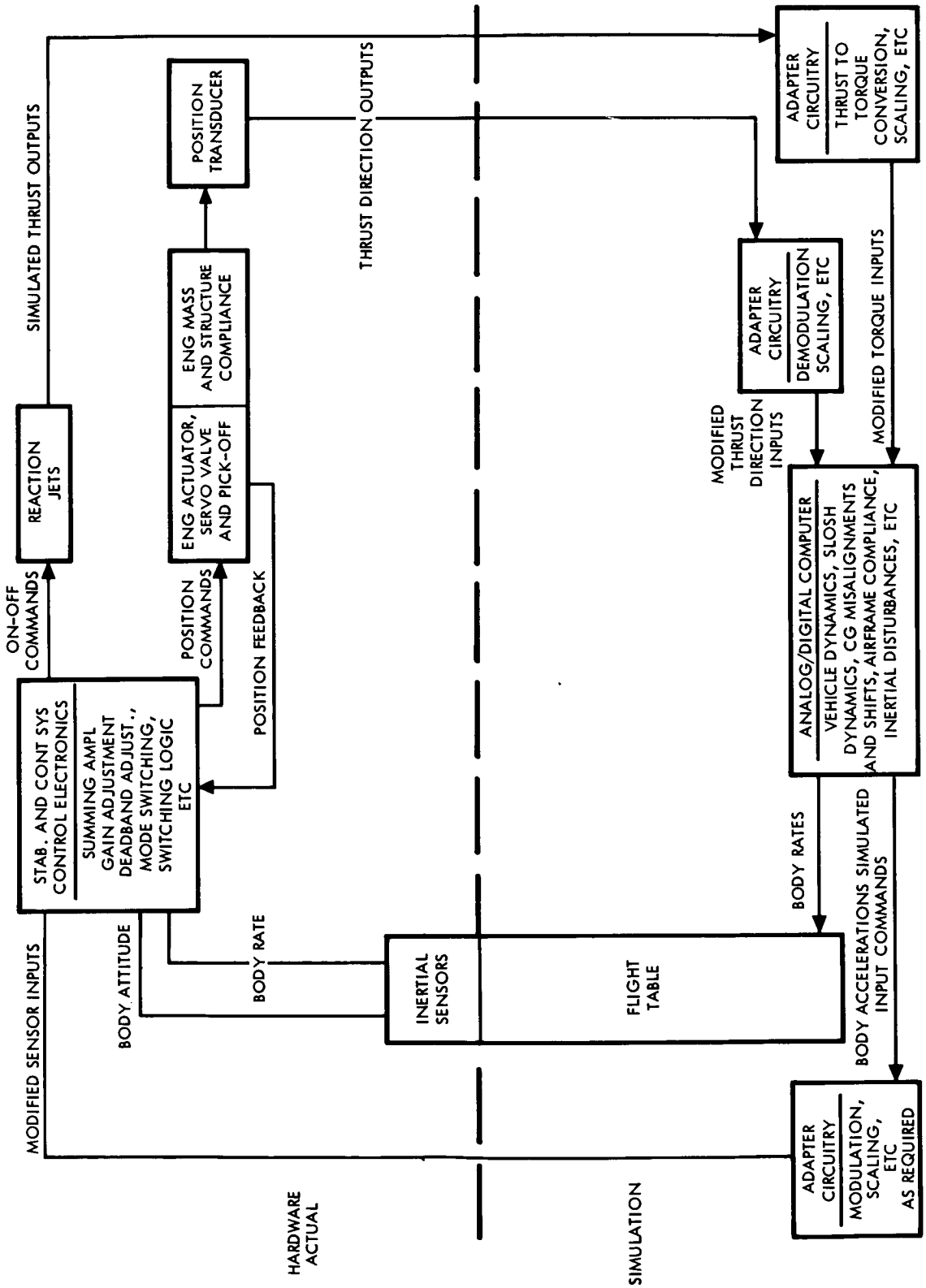


Figure 8-5. Phase IV Test Configuration

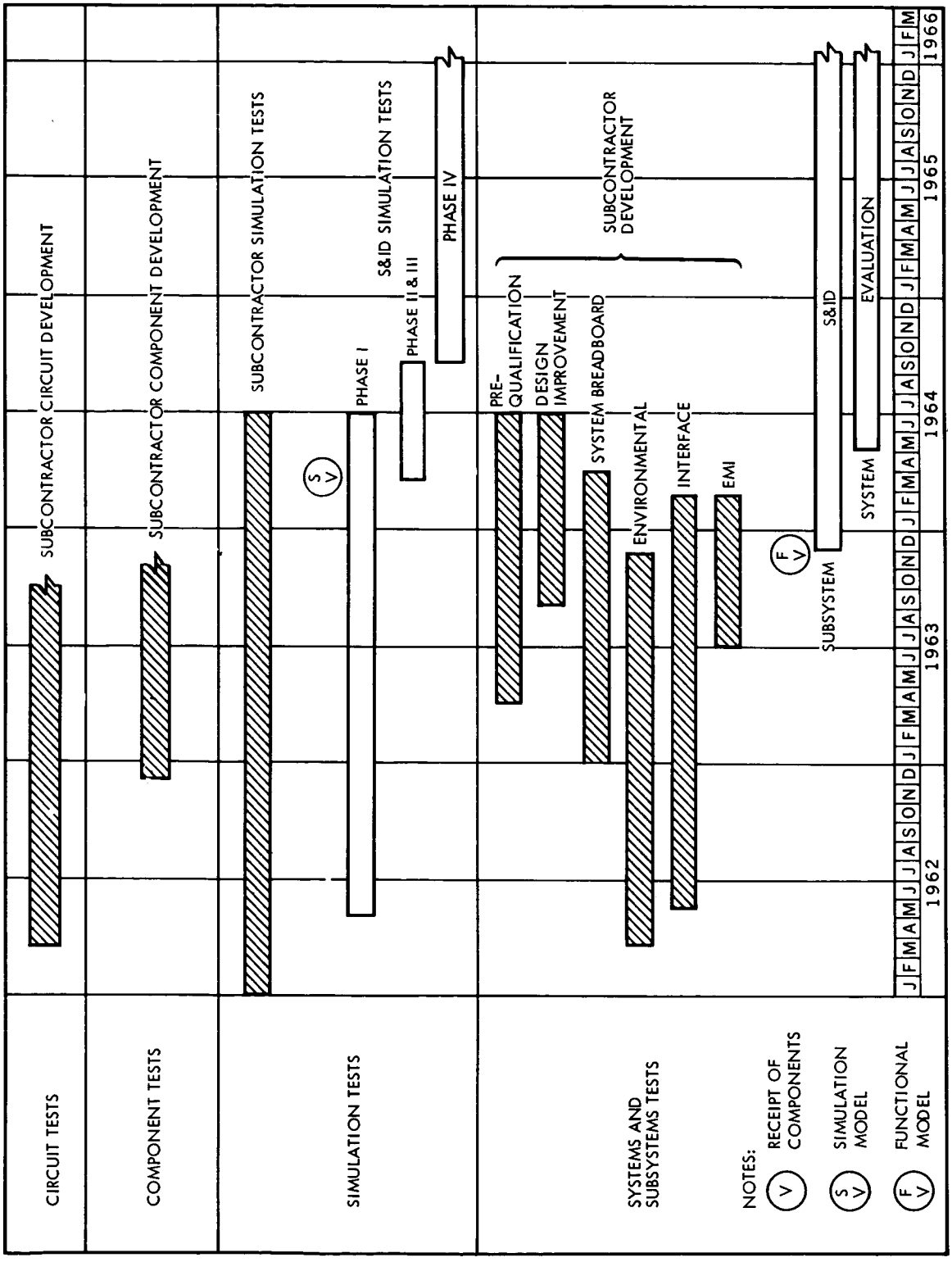


Figure 8-6. Stabilization and Control Test Schedule

9.0 COMMUNICATIONS AND INSTRUMENTATION SYSTEMS*

9.1 SCOPE

The subcontractors will perform development, design verification, qualification, and acceptance tests. The major subcontractor (Collins Radio) will also perform systems-type tests on one set of prototype equipment of that portion of the communications system which is covered by the Collins subcontract. S&ID will verify specified equipment, perform evaluation tests on the complete communications system, and explore interface problems. Development, qualification, and acceptance tests will be performed on the S&ID fabricated antennas, and the 2-KMC high gain antenna will be calibrated and aligned. Detailed equipment tests will be performed by using bench maintenance equipment necessary for performance verification and maintenance. Spacecraft-GOSS compatibility tests will be performed. Only the engineering development, design verification, antenna pattern, evaluation, calibration and alignment tests will be described in this section. Qualification and acceptance test plans will be reported in SID 62-109-3 and SID 62-109-4.

9.2 SUBCONTRACTOR TEST PLAN

9.2.1 Objectives

The objectives of the subcontractor's tests are to establish the feasibility of the design approach and to develop the design in accordance with design specifications, to operational maturity.

9.2.2 Test Plan

9.2.2.1 Major Subcontractor (Collins Radio)

The major subcontractor and the second tier subcontractors will conduct an extensive test program during the design and development of the equipment. The test program will consist of spacecraft equipment tests, to ensure compliance with the equipment specifications, and subsystem tests by the major subcontractor. The tests will be performed on one complete set of E-model equipment of that portion of the communications system which is covered by the Collins subcontract. The equipment consists of the following:

*Entire section reissued

VHF-FM transmitter
VHF-AM transmitter-receiver
Unified S-band equipment (second tier subcontractor-Motorola)
S-band power amplifier
C-band transponder (second tier subcontractor-ACF)
VHF recovery beacon
HF transceiver
Audio center
Premodulation processor
PCM telemetry (second tier subcontractor-Radiation)
Signal conditioning equipment
Data storage equipment (second tier subcontractor-Leach)
VHF multiplexer
R&D VHF omni-antenna equipment (See Paragraph 9.2.2.1.4.)

The major subcontractor's equipment will be defined by the extent of the tests that it has succuessfully completed and by its use, as defined below:

E-Model. The equipment will be in the final package configuration, and will incorporate design changes resulting from developmental testing. All design verification tests will be conducted on this model to upgrade the design to a status that is expected to pass qualification tests.

D-Model. This equipment will incorporate changes resulting from the design verification tests and will contain high reliability components. Qualification tests will be performed on this model.

P-Model. This P equipment will incorporate all design modifications resulting from the qualification program, as well as any changes from the design verification test program obtained after D-model design freeze. This model will be considered qualified for use on manned missions.

9.2.2.1.1 Development Tests. Development tests will be performed early in the design phase on equipment, modules, circuits, and components to determine the feasibility of the circuit design, mechanical design, and component application. The tests primarily are electrical, but some modules and equipment mock-ups will be subjected to thermal and vibration environments to determine their performance under these conditions. All developmental tests will be performed by the design engineers of the major subcontractor or the second tier subcontractor. Electrical tests will be made on breadboard circuits and the results will be used to verify the performance required, or to indicate where changes in the circuitry are needed. In many cases, after the electrical design has been established

[redacted]

with the breadboards, a brassboard model will be built. In this model, the components will be packaged in a manner similar to the expected final configuration. Electrical, exploratory thermal, and vibration tests will be made on the brassboards to obtain information on the effects of the placement of components on electrical, thermal, and vibration characteristics. The E-model design will be established using information obtained from development tests.

9.2.2.1.2 Design Verification Tests. The design verification tests will determine the capability of the equipment to meet operational performance requirements when subjected to selected environments. These tests will include preliminary design proof tests, off-limits tests, and parts application tests. All design verification tests will be conducted by the manufacturer of the equipment; that is, the major subcontractor's second tier subcontractor will conduct all design verification tests on its equipment. A typical time phasing of the design verification test program is shown in Figure 9-1.

9.2.2.1.2.1 Preliminary Design Proof Tests. Preliminary design proof tests will be performed on two early E-models of each equipment by the major subcontractor's, or the second tier subcontractor's, design engineers. The tests will include functional tests under laboratory conditions and normal line voltage, high and low line input voltage tests, environmental tests, and electromagnetic interference (EMI) tests. The objectives of the preliminary design proof test are to evaluate high and low line functional operation; to demonstrate the capability of the equipment to operate under service conditions as specified in MC999-0023, General Specification for Communications and Data Subsystem; and to demonstrate the equipment compliance with the EMI requirements, as specified in MC999-0023. The changes resulting from the functional tests, vibration, and high-temperature tests will be incorporated in the D-model design. All modifications resulting from information obtained from tests occurring after the D-model design freeze will be incorporated into the P-model design.

9.2.2.1.2.2 Part Application Tests. The objective of part application tests is to verify proper part selection and application within the equipment. These tests will determine the factor of safety in part applications with respect to the applicable part parameters, related part specifications, and specified part derating principles. The tests will be conducted on one E-model of each piece of equipment, and will consist of measuring electrical, thermal, and mechanical stresses on parts in their respective applications. Electrical stresses, including voltage and/or current and transient conditions, will be measured on parts during equipment operation under nominal conditions. From the electrical stress measurements and design analysis, temperature critical parts will be determined and the thermal stress on

[redacted]

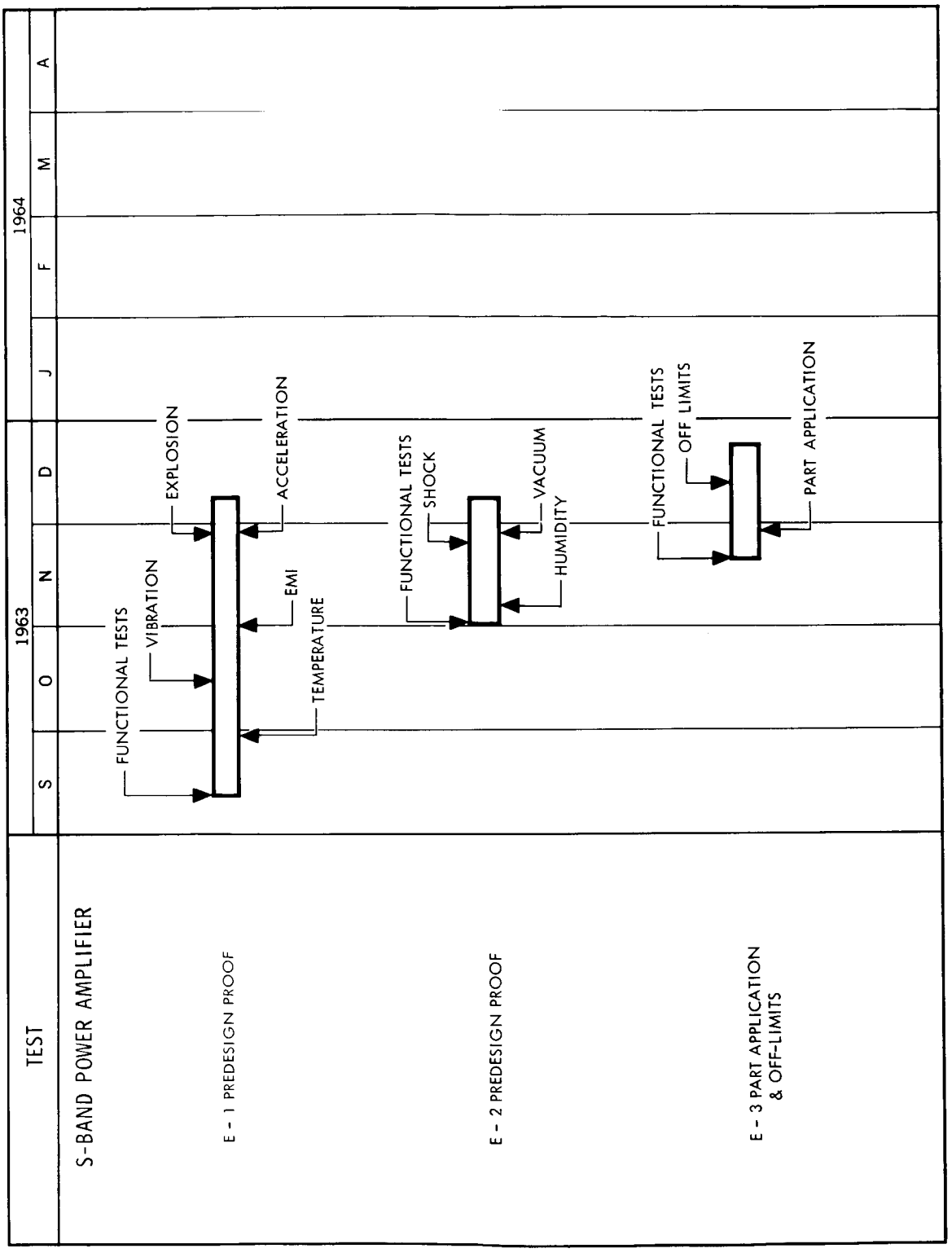


Figure 9-1. Major Subcontractor Typical Design Verification Tests

these parts will be measured. Mechanical stresses, deemed critical by design analysis, will be measured on selected electrical, mechanical, and electro-mechanical parts. The information obtained from part application tests will be incorporated into the P-model design.

9.2.2.1.2.3 Off-Limits Tests. Off-limits tests will be conducted on the same unit used for part application tests after the part application tests have been completed. The objective of off-limits tests is to determine the equipment design margin of safety early in the test program. Each equipment will be subjected to increasing environmental and electrical stress levels beyond the design proof levels until a significant output degradation of the equipment occurs and no further useful performance information can be obtained.

The off-limits test stresses to be investigated during the design verification tests will include combined temperature-voltage, combined random-sine-wave vibration, and shock. The information obtained from these tests will be incorporated into the P-model design.

9.2.2.1.3 Subsystem Tests. A subsystem test will be performed by the major subcontractor to assure compatibility between individual equipment and satisfactory operation as a subsystem. The tests will be performed on one complete set of E-model equipment for which the major subcontractor is responsible. They will consist of electrical integration tests and EMI tests. No environmental tests will be conducted at the subsystem level. The tests will be performed first at the open-system bench test level. The equipment will be connected by a system wiring harness around the test area, and the tests will be conducted in a spacecraft mock-up with a simulated lower equipment bay. The advantage of the open-system bench test is that preliminary problems can be solved away from the confined area of the lower equipment bay. The capsule tests provide a subsystem simulation with the actual spacecraft wiring harness and the equipment installation rack. The information obtained from the subsystem test will be used in the P-model design.

9.2.2.1.4 R&D VHF Omni-Antenna Equipment Test Programs. The R&D VHF omni-antenna equipment program will not be as sophisticated as the test program on other equipment supplied by the major subcontractor. The reason is that this antenna equipment is used only on unmanned R&D missions, and will not see the stringent environments and duty cycles that the other major subcontractor supplied equipment will experience on lunar missions. Development tests will be conducted on the antenna and will consist of electrical tests on both scaled and full-scale models. The purpose of the tests will be to determine the optimum physical shape of the antenna that will provide electrical characteristics to meet the performance requirements specified in MC481-0026, Specification for the R&D VHF Omni-Antenna Equipment.

[redacted]

9.2.2.1.5 Antenna Subcontractors. The subcontractors supplying antenna equipment will conduct an extensive test program during the design and development of the equipment. The tests will include model antenna patterns, full-scale patterns, and development and design verification. The antenna subcontractors are responsible for the following equipment:

Beacon antenna equipment (Radcom)
Recovery antenna equipment (Airborne Instrument Laboratories)
2-KMC high-gain antenna equipment (Avien)

9.2.2.2 Other Spacecraft Equipment Subcontractors

9.2.2.2.1 Television Equipment Test Program (RCA). RCA will conduct an extensive test program during the television equipment design and development. Included in the test program will be development and design verification tests.

9.2.2.2.1.1 Development Tests. Development tests will be conducted by RCA on breadboard circuits and one breadboard unit of the television equipment. The tests will be performed early in the design period, and will consist of unit and circuit functional tests and component evaluations. Information obtained from these tests will be used in the E-model design.

9.2.2.2.1.2 Design Verification Tests. RCA will conduct design verification tests on three E-models of the television equipment. These tests are designed to provide information that will enable RCA to design D-models that will have a high probability of passing the qualification tests. Table 9-1 shows the design verification tests to be conducted, and the utilization of the three E-models.

9.2.2.2.2 Central Timing Equipment (CTE) Test Program (Elgin). Elgin will conduct an extensive test program during the design and development of the CTE. The program will consist of development and design verification tests to assure compliance with the equipment specification (MC456-0006).

9.2.2.2.2.1 Development Tests. Development tests will be conducted early in the design phase on the CTE circuits and the complete breadboard unit. The tests will consist of functional electrical tests on circuits and the unit, along with performance tests under selected environmental conditions. Included in the environmental tests will be high-temperature tests on the CTE breadboard, and an evaluation of the stability of the temperature-compensated oscillator under temperature variations. In addition, circuits and components

[redacted]

will be tested for interference susceptibility. Modifications resulting from information obtained during the initial portion of development tests will be incorporated in the E-model. Information obtained subsequent to the E-model design freeze will be used to aid in the D-model design phase. The development tests will be conducted at the Eglin facility.

9.2.2.2.2.2 Design Verification Tests. Design verification tests will be conducted on one E-model CTE. The tests will be conducted to gain test information that will enable Eglin to update the E-model design to a configuration that has a high probability of passing qualification tests. The tests will be designed to locate significant failure modes; determine the effects of critical single and combined environments, of functional stresses, of combinations of tolerances; and to determine design margins. The combined environments portion of the design verification tests will be conducted by a testing laboratory in the immediate vicinity of Eglin.

Table 9-1. Design Verification Test Program (RCA)

Test Conditions	Sequence of Tests		
	Assembly Number 1	Assembly Number 2	Assembly Number 3
Examination of product	1	1	1
Dielectric strength	2	2	2
Insulation resistance	3	3	3
Redundant circuit	4	4	4
Functional	5	5	5
Leakage	6		6
Humidity		6	
Acoustics		7	7
Vibration	7		8
Acceleration	8		
Electromagnetic interference	9	8	
Explosive atmosphere			9
Oxygen atmosphere	10		
Shock	11		

[redacted]

9.2.2.2.3 Up-Data Link Equipment Test Program (Motorola). Motorola will conduct an extensive test program during the design and development of the up-data link equipment. The program will include development and design verification tests.

9.2.2.2.3.1 Development Tests. Development tests will be conducted by Motorola on breadboard circuits to establish the electronic design. The results of these tests will be used to make any necessary changes in the E-models before their assembly. D-model design will be established on the basis of the development tests.

9.2.2.2.3.2 Design Verification Tests. Design verification tests will be conducted on three E-models of the up-data link equipment. The tests will be conducted to provide test information enabling Motorola to modify the D-model design to a configuration with a high probability of passing qualification tests.

9.2.3 Equipment

The subcontractors will use the following equipment which may be provided by the subcontractor or by a testing laboratory whose services are procured by the subcontractor:

Climate chambers
Humidity chambers
Vibration machines
Shock testers
Acoustic chambers
Vacuum chambers
Explosion chambers
Centrifuges
RFI shield rooms
Antenna pattern ranges
Laboratory test equipment and recorders

The major subcontractor also will provide a command module mock-up for use in the system-type tests.

9.2.4 Facilities

Unit test equipment (UTE) will be provided and used by the subcontractors in the testing of the equipment. The major subcontractor also will provide modified bench maintenance equipment for use in its system-type tests.

[redacted]

[redacted]

9.2.5 Test Schedule

The subcontractor test schedules are shown in Figures 9-2, 9-3, and 9-4.

9.3 S&ID TEST PLAN

9.3.1 Objectives

The objectives of the S&ID tests, on equipment other than antennas, are: to verify that performance of E-model equipment received for engineering tests are within specified limits; to explore any interface problems that may occur after installation of this equipment in a complete communications system breadboard; to isolate and determine the cause of malfunctioning equipment; and to verify the acceptable condition of spare equipment.

The objectives of the S&ID tests of antennas are to calibrate and align the 2-KMC high-gain antenna prior to installation on the S/M, and to develop the S&ID fabricated VHF/2-KMC scin antennas.

The objectives of the spacecraft—GOSS compatibility tests are:

1. To determine the compatibility of the spacecraft communications system with the GOSS interfaces;

2. To verify the spacecraft communications system performance with GOSS under the constraints of the mission;

3. To investigate engineering changes designed to eliminate incompatibilities between spacecraft, communications system and GOSS;

4. To test engineering concepts for optimizing the over-all communications link; and

5. To evaluate the modified GOSS-spacecraft communications system performance to ensure the removal of incompatibilities.

9.3.2 Test Plan

9.3.2.1 Equipment Tests on Bench Maintenance Equipment (BME)

Tests will be performed as necessary using the BME for performance, verification, and maintenance. Tests made on the BME will enable isolation to the module or lowest plug-in unit level. After the replacement with a spare module, a modified electrical portion of the equipment acceptance

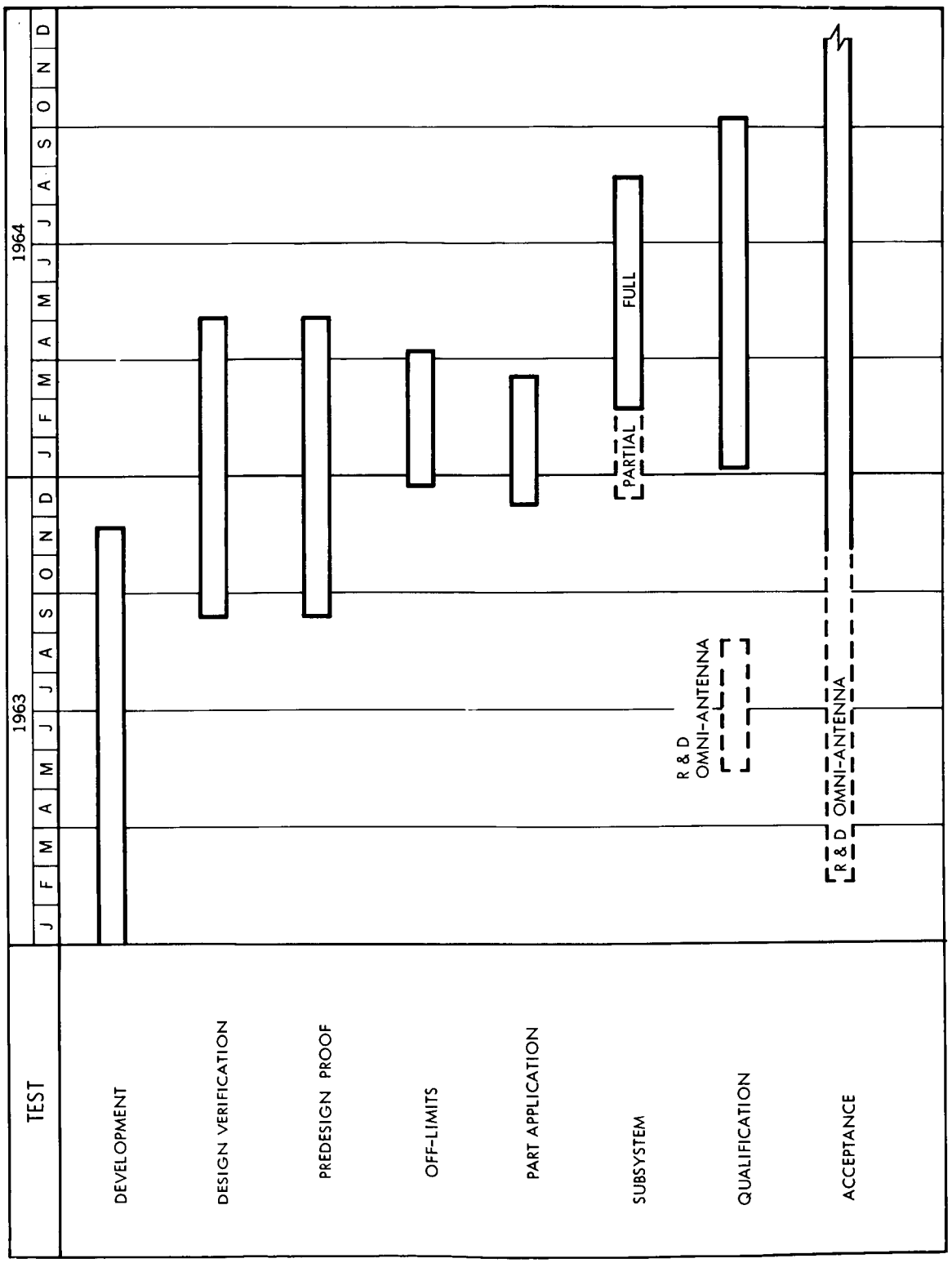


Figure 9-2. Major Subcontractor Spacecraft Equipment Tests

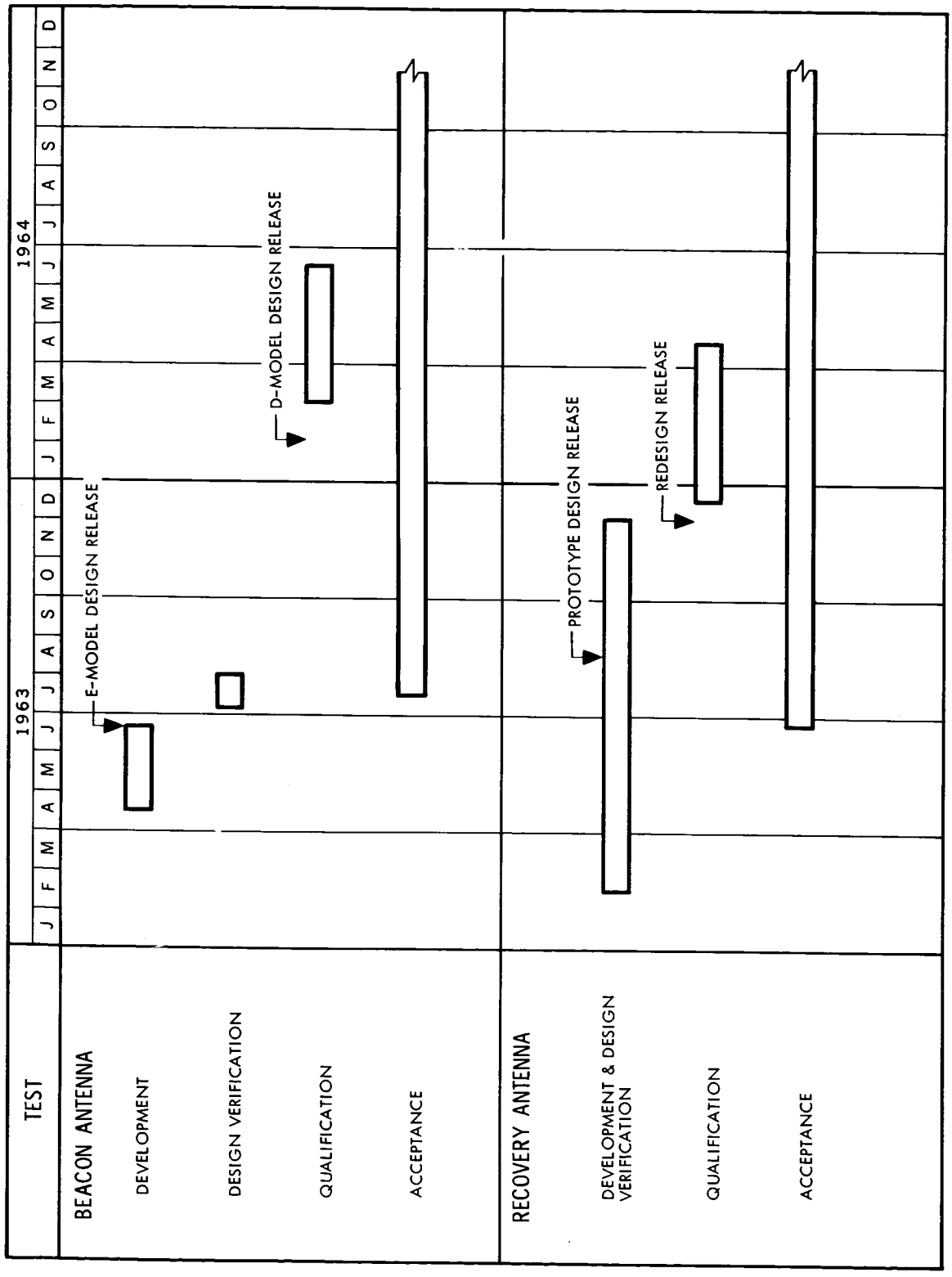


Figure 9-3. Operational Antenna Subcontractor Equipment Tests

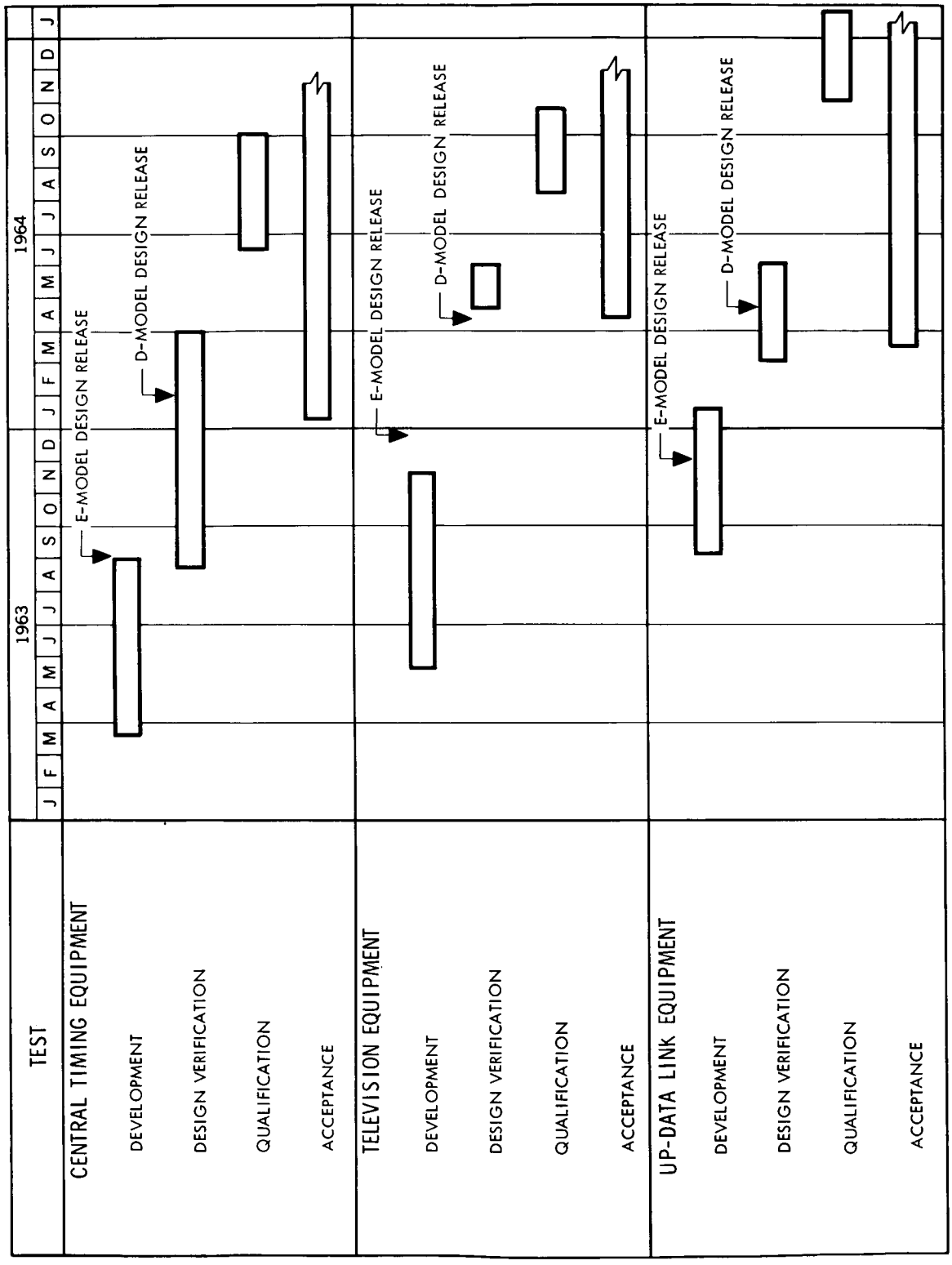


Figure 9-4. Other Spacecraft Equipment Subcontractor Tests

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[redacted]

test will be performed on the BME to return the package to the status of an acceptable spare. This modified electrical portion of equipment acceptance tests will be performed on spare equipment, at specified intervals, to verify their status as acceptable spares.

9.3.2.2 Engineering Tests on E-Model System

Two or more E-models of all equipment except antennas and central timing equipment will be delivered to NAA after completion of the in-house design verification tests by the subcontractors. One set of this equipment will be used by NAA in the spacecraft—GOSS compatibility test program, and the other set will be installed in a communications system breadboard in the laboratory. This will afford the first opportunity to integrate the complete system, other than the tests of the system which will be started in B-14, at approximately the same time. The test programs for the engineering breadboard system and for the system in B-14 will complement each other and form an effective support to the operational spacecraft systems. The engineering breadboard system cannot accurately simulate the interference and interface problems resulting from the spacecraft wiring and other systems. This can only be achieved adequately in the in-house spacecraft program. However, system tests can be performed on the engineering breadboard system to investigate internal system interface problems not caused by spacecraft installation effects. These tests that will be performed in the laboratory will reduce the requirement for scheduling test time on the spacecraft that normally would interfere with other spacecraft system tests. Freed from the confined area of the lower equipment bay in the spacecraft, the investigation of the problem and the determination of an optimum solution can be accelerated. Verification of the solution will be accomplished in the spacecraft. Use of the engineering breadboard system will permit the use of a greater variety of test equipment in the solution of problems than would be possible with the equipment installed in the spacecraft. The engineering breadboard system will be used: to explore the variation of equipment parameters under unique operating conditions; as a training aid; to obtain information when preparing or correcting process specifications; and as an engineering tool to evaluate the system effects of new equipment and techniques.

A test program to verify that the performance of the E-model equipment will be within specified limits and to explore any interface problems within the communications system is illustrated by the equipment and system tests that follow.

9.3.2.2.1 VHF-FM Transmitter

9.3.2.2.1.1 Equipment Test. Proper operation of the VHF-FM transmitter will be verified by the following tests.

[redacted]

[redacted]

1. Power Supply Voltages. Power supply voltages will be measured at the test points provided.

2. Output Power. The transmitter output will be terminated in a load simulating that of the spacecraft through a dual directional coupler with coupling arms that will be used to measure the incident and reflected power. The unmodulated power output will be not less than 10 watts.

3. Output Frequency. The coupled output from the forward terminal of the dual directional coupler will be terminated in a frequency counter to measure the output frequency with no modulation applied.

4. Frequency Deviation. The transmitter output from the forward terminal of the dual directional coupler will be terminated in the input connector of a transfer oscillator, which will be used in conjunction with a frequency counter and oscilloscope to measure frequency deviation by the bow-tie method. With the transmitter modulated by a sine wave of proper amplitude at a number of frequencies between 20 cps and 50 kc, the frequency deviation will measure ±125 kc within a ±10-kc tolerance.

5. Frequency Deviation Linearity. With the same test setup as in test 4, the transmitter will be modulated by a 16-kc sine wave in increments of 0.5 volts peak-to-peak, and will result in a voltage versus frequency plot linear within ±2.5 percent over the peak-to-peak deviation of 250 kc.

6. AFC Voltage. The AFC voltage will be measured at the test point provided.

9.3.2.2.1.2 System Test. Proper operation of the VHF-FM transmitter in conjunction with the other equipment in the communications system will be verified by tests 1, 2, 4, and 6 of paragraph 9.3.2.2.1.1.

9.3.2.2.2 VHF-AM Transmitter - Receiver

9.3.2.2.2.1 Equipment Test. Proper operation of the VHF-AM transmitter-receiver will be verified by the following tests.

1. Receiver Sensitivity. A VHF signal of 70-percent amplitude modulated by 1000 cps corresponding to each of the receiver frequencies will be applied to the receiver input. The signal level that is required to produce a 10-db signal plus noise-to-noise ratio at the receiver audio output will be measured.

[redacted]

2. Receiver Distortion. The over-all receiver distortion will be measured at the receiver audio output with a distortion analyzer when a VHF-AM signal is applied to the receiver input.

3. Receiver Frequency Response. The frequency response as measured with a meter having a 600-ohm impedance will be flat within ±3 db from 300 to 2300 cps when referenced to 1000 cps.

4. Power Supply Voltage. The power supply voltage will be measured at the test points provided.

5. Transmitter Output Power. The transmitter output power level will be measured with the transmitter terminated in a load with a VSWR of 2:1 through a directional coupler with a coupling arm that will be used to measure the incident power while operating with no modulation.

6. Transmitter Output Frequency. While operating in the same mode as in test 5, the output frequency will be measured by connecting the coupling arm to a frequency counter.

7. Transmitter Modulation. The percent of amplitude modulation of the transmitter carrier will be measured while a 1000-cps tone is applied to the transmitter audio input.

8. Transmitter Distortion. The distortion of the transmitter carrier and its modulation envelope will be measured while a 1000-cps modulation voltage is supplied to the transmitter at an amplitude just below the clipping level of the transmitter, with its output properly connected to a calibrated receiver and distortion analyzer.

9.3.2.2.2.2 System Test. Proper operation of the VHF-AM transmitter-receiver in conjunction with the other equipment in the communications system will be verified by the following tests.

1. Tests 4, 5, and 6 of paragraph 9.3.2.2.2.1 will be used.

2. The intelligibility of voice transmission and reception will be verified. A method of measuring intelligibility will be determined.

9.3.2.2.3 Unified S-Band Equipment.

9.3.2.2.3.1 Equipment Test. Proper operation of the unified S-band equipment will be verified by the following tests.

[redacted]

1. Power Supply Operation. The power supply voltages will be measured at the access points.

2. Primary Power. The primary power will be measured. The maximum power for any equipment operating mode will be 14 watts.

3. Transmitter Frequency Auxiliary Oscillator Mode. The output frequency will be measured with no modulation into the transmitter.

4. Transmitter Frequency, VCO Mode. The output frequency will be measured while applying an input signal, with its amplitude set at a value which gives a specified AGC voltage to the receiver. The input signal will be varied over the specified frequency range in 10-kc steps. The output frequency will be 240/221 times the input frequency.

5. Nominal Assigned Frequencies, VCO Mode. The input frequency will be measured with an input signal set to give a specified output frequency, as in test 4 above. The ratio of output to input frequencies will be 240/221.

6. Output Power, Auxiliary Oscillator Mode. The transmitter output power level will be measured with no modulation applied. The power level will be 250 to 400 mw in either PM or FM modes.

7. Output Power, VCO Mode. The transmitter output power level will be measured with no modulation while applying an input signal to the receiver with its amplitude set as in test 4 above, but being swept in frequency over the specified range. The power level will remain between 250 and 400 mw in either PM or FM modes.

8. Receiver Threshold. For an input signal with frequency of that measured in test 5 above, the threshold will be measured as the amplitude of input signal required to set the AGC voltage to the specified value.

9. Receiver Threshold Variation. From test 8 above, the input signal frequency will be varied ±60 kc, and verification will be made that the input amplitude need not be varied more than 0.5 db to maintain the AGC level, as given in test 8 above.

10. Receiver Dynamic Range. From test 8 above, verification will be made that the input signal amplitude can be increased 80 db without limiting of the AGC voltage.

11. Modulation Phase Detector. The up-voice output will be measured while a test signal, phase modulated by a 30-kc signal, is applied to the receiver input. The output will be 1.00±0.05 volts per radian of carrier deviation by the 30-kc signal.

12. Ranging Operation. The transmitted output signal will be detected with the equipment in the ranging mode and while a signal, as determined in test 5 above, which has been phase modulated by a 500-kc square wave to a 1-radian deviation, is applied to the receiver input. The detected signal will be examined for the proper characteristics.

13. Output Spectrums. The transmitter output spectrum will be recorded when the modulators have been applied to their inputs, a set of specified tones, one at a time. The auxiliary oscillator mode will be used.

9.3.2.2.3.2 System Test. Proper operation of the unified S-band equipment, in conjunction with the other equipment in the communications system, will be verified by the following tests.

1. Tests 6, 7, 8, 9, 12, and 13 of paragraph 9.3.2.2.3.1 will be used.

2. The signal from this equipment will be checked for degradation by other equipment.

9.3.2.2.4 S-Band Power Amplifier Equipment

9.3.2.2.4.1 Equipment Test. Proper operation of the S-band power-amplifier equipment will be verified by the following tests.

1. Power Output, Equipment Off. A 250-mw input signal at the assigned frequency will be applied at the input, and an output signal of 165-mw minimum will be verified.

2. Power Output, Low Gain. With an input signal identical to that in test 1 above, and two minutes or more after equipment turn-on, an output signal of 3.3 (+0.6, -0.4) watts will be verified.

3. Power Input, Low Gain. When operated in test 2 above, a primary power input not exceeding 35 watts will be verified.

4. Power Output, High Gain. With an input signal identical to that in test 1 above, and two minutes or more after equipment turn-on, an output signal of 14.5 watts or more will be verified.

[redacted]

5. Power Input, High Gain. When operated in test 4 above, a primary power input not exceeding 80 watts will be verified.

6. Switching Functions. The following operations will be verified. When the equipment is switched on, the output signal power will remain at the level given in test 1 above for the specified time delay. The output signal will be one of those given in test 2 or test 4 above, with the primary input power being not more than 10 watts until the end of the delay time when it will increase to one of the levels given in test 3 or 5 above. The primary input power and output signal will change levels according to test 3 or 5, and test 2 or 4 above by proper command.

7. Signal Isolation. The signal level to the unified S-band equipment receiver from the diplexer during tests 1, 2, and 4 above will be verified to be attenuated a minimum of 60 db relative to the S-band power amplifier output. The signal level to the unified S-band equipment receiver from the diplexer will be verified to be not less than -1 dbm when a 0-dbm signal at a frequency 221/240 of that given in test 1 above is applied to the antenna connection (with proper switch actuation).

9.3.2.2.4.2 System Test. Proper operation of the S-band power amplifier equipment, in conjunction with the other equipment in the communications system, will be verified by the following test. The various modes of operation will be verified similarly to test 6 of paragraph 9.3.2.2.4.1, except that the power levels may not be measured.

9.3.2.2.5 C-Band Transponder

9.3.2.2.5.1 Equipment Test. Proper operation of the C-band transponder will be verified by the following tests.

1. Receiver Sensitivity. A test signal at the assigned frequency will be applied to each receiver channel in turn to determine the triggering sensitivity. The test signal will have a repetition rate of 500 pps. The sensitivity will be checked for a single-pulse interrogation and for a pre-set two-pulse coded interrogation.

2. Receiver Tuning. Each receiving channel will be checked to determine that it is tuned to the assigned frequency within ±1 mc.

3. Transmitter Output Power. The peak pulse power of the transmitter will be determined with the transponder being triggered at a 500-pps rate.

4. Transmitter Output Frequency. The output signal of test 3 will be connected to a wavemeter to determine that the output is at the assigned frequency, within ±4 mc.

5. Comparator Operation. Verification of proper operation of the comparator will be obtained by applying appropriate signals to alternate inputs of the transponder.

6. Random Noise Firing. With the receiver inputs terminated in dummy loads, the random noise firing of the transmitter will be checked with a counter to verify that it is within the acceptable limit.

7. Countdown. The transmitter reply rate will be monitored with a counter to determine that it does not exceed the pre-set rate when the receiver is intentionally over-interrogated.

9.3.2.2.5.2 System Test. Proper operation of the C-band transponder, in conjunction with the other equipment in the communications system, will be verified by the following tests.

1. Tests. Tests 1, 3, and 5 of paragraph 9.3.2.2.5.1 will be used.

2. Random Noise Firing. With the system installed in its flight-ready configuration and set for single-pulse interrogation, the transmitter will be monitored with a counter to verify that communications equipment signals do not cause excessive noise firing.

9.3.2.2.6 VHF Recovery Beacon

9.3.2.2.6.1 Equipment Test. Proper operation of the VHF recovery beacon will be verified by the following:

1. Power Supply Voltages. The power supply voltages will be measured at the test points provided.

2. Output Power. The VHF recovery beacon will be terminated in a load with a VSWR of 2:1 through a directional coupler with a coupling arm that will be used to measure the incident power.

3. Output Frequency. The output of the coupler arm will be fed into a counter for a direct measurement of frequency.

4. VHF/BCN Auto Mode. The proper operation of the VHF/BCN auto mode will be verified.

[redacted]

9.3.2.2.6.2 System Test. Proper operation of the VHF recovery beacon, in conjunction with the other equipment in the communications system, will be verified by tests 1 and 2 of paragraph 9.3.2.2.6.1.

9.3.2.2.7 HF Transceiver

9.3.2.2.7.1 Equipment Test. Proper operation of the HF transceiver will be verified by the following tests.

1. Receiver Sensitivity (AM and SSB). The receiver sensitivity will be measured by means of the minimum discernible signal (MDS) technique. A calibrated signal generator and an HF spectrum analyzer should be used. In the SSB position, the transmitter will be modulated with a 1000-cps tone.

2. Receiver AGC Voltage (AM and SSB). The receiver AGC voltage will be measured with a high input impedance VTVM. The RF input voltage will be varied from 10 to 100,000 microvolts, and AGC voltage will be monitored to ascertain that it remains within specified limits.

3. Transmitter Carrier Output Power (AM). The transmitter carrier output power will be determined without modulation being applied and with the transmitter tuned to optimum performance. An in-line directional coupler will be connected in the circuit so that its coupling arm can be used to monitor the incident power. The transmitter will be terminated into a nominal 50-ohm resistive load.

4. Transmitter Output Frequency (AM). The transmitter output frequency will be measured by connecting a high-frequency counter to the coupling arm of the directional coupler.

5. Hum and Noise Output (AM). The hum and noise output of the transmitter will be monitored on an oscilloscope with the equipment operating at rated power output.

6. Voltage Standing Wave Ratio (AM). The output of the transmitter will be connected to an in-line directional coupler. VSWR will be read on a standing wave ratio bridge, or equivalent. The transmitter will be operated at rated power and terminated into a nominal 50-ohm resistive load.

7. Transmitter Power Output (SSB). The transmitter output power will be measured by applying a single-tone audio signal to the

input and monitoring power output through a directional coupler on a suitable indicating device. The transmitter will be terminated with a nominal 50-ohm resistive load.

8. Transmitter Spurious Output (SSB). The transmitter output intermodulation distortion products and unwanted sidebands will be measured using spectrum analysis techniques. The output of the transmitter will be connected to an in-line directional coupler and terminated into a nominal 50-ohm resistive load.

9. Transmitter Carrier Suppression (SSB). The suppression of the RF carrier will be measured with a spectrum analyzer to verify that the carrier remains within the specified limits. The output of the transmitter will be displayed on the spectrum analyzer, and the level of sideband will be compared to the level of suppressed carrier to establish the degree of suppression.

10. Transmitter Noise Level (SSB). The output of the transmitter will be connected to an oscilloscope through a directional coupler. The transmitter will be connected to a nominal 50-ohm resistive load. With the transmitter operating at rated output, noise on the carrier will appear as a ripple on the oscilloscope display.

9.3.2.2.7.2 System Test. Proper operation of the HF transceiver, in conjunction with the other equipment in the communications system, will be verified by measuring the intelligibility of voice transmission and reception will be verified in the SSB and AM modes. A method of measuring intelligibility will be determined.

9.3.2.2.8 Audio Center Equipment

9.3.2.2.8.1 Equipment Test. Proper operation of the audio center equipment will be verified by the following tests.

1. AVC Threshold Level of Microphone and Earphone Channels. Using a 1000-cps signal, the AVC threshold input signal level will be verified to be between -16 and -10 dbm for each of the microphone channels, and between 1.27 and 2.53 volts for each of the earphone channels. The signal source impedance will be 600 ohms

2. Channel Gain of Microphone and Earphone Amplifier Channels. Using a 1000-cps tone with the input levels set at AVC threshold, outputs of 0 dbm across 600 ohms for each of the microphone amplifier channels, and 20 dbm across 600 ohms for each of the earphone amplifier channels, will be verified. In each amplifier, an input signal increase of 20 db will cause the output to increase no more than 4 db.

[redacted]

3. Frequency Response of Microphone and Earphone Amplifier Channels. The frequency response of each of the microphone and earphone amplifier channels will be measured at a level just below the AVC threshold to verify that the response is constant, within +1 and -3 db, relative to 1000 cps over the range of 300 to 3000 cps. Source and load impedances will be 600 ohms.

4. AVC Attack Time of Microphone and Earphone Channels. The AVC attack time of each of the microphone and earphone channels will be measured by observing the output while a 1000-cps signal at the input is stepped from the AVC threshold value to a value 10 db above threshold.

5. AVC Release Time of Microphone and Earphone Channels. The AVC release time of each of the microphone and earphone channels will be measured by observing the output while a 1000-cps signal at the input is stepped from a value 10 db above AVC threshold to the threshold value.

6. Distortion. The distortion of each of the microphone and earphone amplifier channels will be measured using an input signal level 20 db above the AVC threshold. Source and load impedances will be 600 ohms.

7. Internal Noise. The internal noise level of all audio channels will be measured at each of the three modulation outputs and at the earphone output of each audio center module.

8. VOX Sensitivity. The sensitivity of the VOX circuitry in each audio center module will be measured by applying a 1000-cps tone to each microphone input and monitoring the side tone in the earphone output of the same module. The VOX sensitivity control will be capable of controlling the output signal with a variation of the input signal from +10 to -10 dbm.

9. VOX Attack and Release Times. The attack time and release time of the VOX circuitry in each audio center module will be measured by applying a 1000-cps signal to each microphone input and monitoring the dc voltage at one of the two transmitter keying circuits.

10. Isolation. Isolation between receiver inputs will be measured by applying a 1000-cps tone at a level of 0.8 volts rms at one of the three receiver inputs and measuring the signal at each of the other

[redacted]

[redacted]

two receiver inputs. All three inputs will be terminated with source impedance of 600 ohms. With any combination of switching of the receiver inputs, the isolation will be at least 50 db. Isolation between modulation outputs will be measured by applying 1000-cps tone to one of the three modulation outputs and measuring the signal at each of the other two modulation outputs. The tone at the modulation output can be obtained by applying a 0-dbm signal to the microphone input of one of the audio center modules. All three modulation outputs will be terminated with load impedances of 600 ohms. With any combination of switching of the modulation outputs, the isolation will be at least 30 db.

9.3.2.2.8.2 System Test. Proper operation of the audio center equipment in conjunction with the other equipment in the communications system will be verified by the following tests.

1. Intercom Operation. A voice input will be applied to the microphone at each astronaut position and monitored on the earphone outputs at the other two positions for verification of intelligibility, VOX and PTT operation, volume control adjustments, balance control adjustments, and side-tone attenuation.

2. Communications and Data Storage Operation. The intelligibility of voice recording and playback on the data storage equipment and the transmission and reception over the RF links will be verified. VOX and PTT operation will be verified. A method of measuring intelligibility will be determined.

9.3.2.2.9 Premodulation Processor Equipment

9.3.2.2.9.1 Equipment Test. Verification of the proper operation of the premodulation processor equipment will be made so that, with no adjustments, the premodulation processor will produce the outputs for the various modes shown in Table 9-2, with the inputs shown in Table 9-3.

9.3.2.2.9.2 System Test. Proper operation of the premodulation processor equipment in conjunction with the other equipment in the communications system will be verified by the following procedure. Signals from the related equipment will be used as inputs to the premodulation processor, and outputs will be sent to the related equipment as shown in Tables 9-2 and 9-3.

9.3.2.2.10 PCM Telemetry Equipment

9.3.2.2.10.1 Equipment Test. Proper operation of the PCM telemetry equipment will be verified by the following tests.

[redacted]

[redacted]

Table 9-2. Premodulation Processor Outputs

Switch	Switch Position and Mode	Output to	Output
4	Emergency voice	USBE (FM-2)	3 kc analog voice, 0.26 v peak
	Normal voice	USBE (PM)	1.25 mc VCO, 0.84±0.04 v peak (voice)
		USBE (PM)	Biphase 1.024 mc PCM, 1.1±0.05 v peak
	Emergency key	USBE (PM)	512 kc sine wave, 1.1±0.05 v peak
5	Ranging A	USBE (PM)	1.25 mc VCO, 0.84±0.04 v peak (voice)
	Off		
	Ranging B	USBE (PM)	1.25 mc VCO, 0.84±0.04 v peak (voice)
		USBE (PM)	Biphase 1.024 mc PCM, 1.1±0.05 v peak
6	Tape**	USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice, RT)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak (S)
		USBE (FM-1)	9 FM channels, 0.0675±0.005 v peak (S)
	Off		
	Analog	USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice, RT)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak (RT)
		USBE (FM-1)	9 FM channels, 0.0675±0.005 v peak (RT)
7	TV	USBE (FM-1)	0 to 500 kc TV, 1±0.05 v peak
		USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak
	Off		
	Relay	USBE (FM-1)	0 to 13 kc biomed data, 0.203±0.01 v peak
		USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak
12	PCM	VHF-FM transmitter	Filtered PCM, 1.5±0.15 v peak
	Off		
	Relay	VHF-FM transmitter	Filtered PCM, 1.0±0.1 v peak
		VHF-FM transmitter	0 to 13 kc biomed data, 0.6±0.066 v peak
16	Record***	DSE	PCM data, same as input
		DSE	9 analog channels, same as input
	Off		
	Play (Provides power to DSE playback electronics)		
19	PCM (PCM playback only)	USBE (FM-1)	9 FM channels, 0.0675±0.005 v peak (RT)
		VHF-FM transmitter	Filtered PCM, 1.5±0.15 v peak (S)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak (S)
		USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice, RT)
		VHF-FM transmitter	Filtered PCM, 1.5±0.15 v peak (S)
	Normal**, analog + PCM playback	USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak (S)
		USBE (FM-1)	9 FM channels, 0.0675±0.005 v peak (S)
		USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice, RT)
	Analog**, analog playback only	USBE (FM-1)	9 FM channels, 0.0675±0.005 v peak (S)
		UHF-FM transmitter	Filtered PCM, 1.5±0.15 v peak (RT)
		USBE (FM-1)	Biphase 1.024 mc PCM, 0.233±0.015 v peak (RT)
		USBE (FM-1)	1.25 mc VCO, 0.266±0.01 v peak (voice, RT)

*All of the above mode switches are the three-position toggle type.

PCM data may be at high or low bit rates (51.2 or 1.6 KB/S).

Up-voice and up-data outputs to the audio center and up-data decoder may be provided during all of the above modes of operation.

Abbreviations

DSE - data storage equipment
PCM - pulse coded modulation
PMP - premodulation processor
USBE - unified S-band equipment
VCO - voltage controlled oscillator
S - stored data from the DSE
RT - real time

**Voice playback is provided on one of the nine FM channels by the DSE.

***Selects the record mode of the PMP. Any one of the other modes may be used at the same time.

[redacted]

Table 9-3. Inputs to Premodulation Processor

Input From	Voltage Level	Frequency
PCM equipment	6±0.5 v = 1; 0(+0.5, -0)= 0 0 to 6v	51.2 KB/S or 1.6 KB/S 512 kc (square wave)
Central timing equipment	0 to 3v	512 kc (square wave)
Key	0 v	dc
Audio center	1.38(+0.9, -0.65) v peak	0 to 3 kc
TV equipment	2.0±0.1 v peak to peak	0 to 500 kc
Dist. panel	0 to 5 v (18 inputs)	5 kc maximum
Biomed from VHF-AM receiver	2.27±0.25 v peak	13 kc maximum
USBE	0.2 to 5.0 v peak 0.2 to 5.0 v peak	30±7.5 kc (up-voice) 70±5 kc (up-data)
DSE	6±0.5 v = 1;0(+0.5, -0) = 0 0 to 5 v (9 inputs)	51.2 KB/S (recorded) 5 kc maximum (recorded)

[redacted]

1. Verification will be made that all inputs required for proper operation are as specified. These inputs will include (excluding S/C measurement signals) (1) timing signals from the spacecraft central timing equipment, 512-kc and 1-cps square waves measure frequency, amplitude, wave shape, and phase relationship and (2) power—115 volts, 400 cps, 3 phase; measure frequency, voltage, phase, load balance, and total power.

2. A go status for all PCM telemetry condition (go, no-go) signals will be verified.

3. Verification will be made that analog operating voltages are within the specified tolerances. These will include all calibrate voltages and all digital logic supply voltages.

4. A selected number of internal digital programming signals will be verified for proper sequencing, waveform, and frequency.

5. All digital output timing signals will be verified for specification compliance.

6. PCM data output pulse trains will be verified for the occurrence of special digital words with appropriate decommutation equipment. Some gating pulses will be available at the access connector to simplify the required test equipment.

7. Measurement input signals will be simulated at the data distribution panel, and the PCM equipment data outputs will be correlated with the known inputs. This will be a gross check to identify faulty channels.

8. Measurement input signals will be controlled as in test 7, except that the data outputs will be recorded digitally. The resultant tapes will be analyzed at the data acquisition and recording station to determine the performance of individual PCM channels.

9. As a supplementary test to test 8, the PCM data output pulse trains will be evaluated for bit error rate and its effects with various amounts of injected noise.

9.3.2.2.10.2 System Test. Proper operation of the PCM telemetry equipment in conjunction with the other equipment in the communications system will be verified by tests 1, 2, 3, and 5 of paragraph 9.3.2.2.10.1.

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9.3.2.2.11 Signal Conditioning Equipment

9.3.2.2.11.1 Equipment Test. Proper operation of the signal conditioning equipment will be verified by the following tests.

1. Verification will be made that, with proper adjustments, the dc amplifiers will produce an output of 0 to 5 volts dc with inputs of 0 to 20 mw dc and all intermediate ranges through 0 to 250 mv dc for types 01, 03, 04, 05, and 06; 0 to 250 mv dc and all intermediate ranges through 0 to 7 volts dc for type 02. Types 03, 04, 05, and 06 are dc amplifiers with the inactive bridge elements incorporated within. Verification will be made that, with proper adjustments, the differential bridge amplifier will produce an output of 0 to 5 volts dc directly proportional to inputs from strain gages and temperature sensors whose resistance varies from 100 ohms to 23.5 kilohms nominal.

2. Verification will be made that, with proper adjustments, the attenuators will produce an output of 0 to 5 volts dc with inputs of 0 to 7 volts dc and all intermediate ranges through 0 to 50 volts dc for type 40; 0 to 7 volts dc and all intermediate ranges through 0 to 50 volts dc for type 41; 28±4 volts dc expanded scale for type 42.

3. Verification will be made that, with proper adjustments, the biphase demodulators will produce an output of 0 for an input signal of 0.5 volts rms and all intermediate ranges through 5 volts rms 180 degrees out of phase with the reference signal, an output of 2.5 volts dc for a 0 input signal, and an output of 5 volts dc for an input signal of 0.5 volts rms and all intermediate ranges through 5 volts rms in phase with the reference signal for type 30. The type 31 will perform in the same manner, except that the signal input values will be 5 volts rms and all intermediate ranges through 50 volts rms. The reference signal will be the same frequency as the input signal with amplitudes of 26, 50, or 115 volts rms ±2 percent.

4. Verification will be made that, with proper adjustments, the frequency converters will produce an output of 0 to 5 volts dc directly proportional to the input frequency, 0 volts dc output at 380 cps, and 5 volts dc output at 420 cps in the range of 105 volts rms to 150 volts rms.

5. Verification will be made that, with proper adjustments, the ac to dc converters will produce an output of 0 to 5 volts dc with

[redacted]

inputs of 0 to 5 volts and all intermediate ranges through 150 volts rms for type 10, and expanded scale 115 volts rms from 105 to 125 volts rms for type 11. The input frequency range will be from 400 cps to 3200 cps.

6. Verification will be made that, with proper adjustments, the low-gain dc amplifiers will produce an output of 0 to 5 volts dc with inputs of ±2.5 volts dc and all intermediate ranges to ±35 volts dc for type 20.

9.3.2.2.11.2 System Test. Proper operation of the signal conditioning equipment in conjunction with the other equipment in the communications system will be verified by the tests, as in paragraph 9.3.2.2.11.1, performed on one of each type conditioner.

9.3.2.2.12 Data Storage Equipment.

9.3.2.2.12.1 Equipment Test. Proper operation of the data storage equipment will be verified by the following tests.

1. Verification will be made that, with proper adjustments, the analog channels will record a 0- to 5-volt, peak-to-peak, 50-cps to 10-kc signal, and, upon playback, reproduce the recorded signal within the required tolerances.

2. Verification will be made that, with proper adjustments, the digital electronics will convert a 0- and 6-volt, serial NRZ, 51.2-kilobit PCM signal to four parallel signals and record them along with a clock signal. Upon playback, the digital electronics will reproduce the parallel signals and convert them to a serial PCM signal identical to that which was presented at the input, within the required tolerances.

9.3.2.2.12.2 System Test. Proper operation of the data storage equipment in conjunction with the other equipment in the communications system will be verified by tests 1 and 2 of paragraph 9.3.2.2.12.1.

9.3.2.2.13 Central Timing Equipment.

9.3.2.2.13.1 Equipment Test. Proper operation of the central timing equipment will be verified by the following tests.

1. Verification will be made that with the 1024-kc input present and with all outputs terminated in 100-ohm loads:

a. All outputs will have an amplitude of 3±0.3 volts on no greater than 50-mv dc offset.

b. The 512-kc outputs will have a 10- to 90-percent rise and fall time of no greater than 100 nanoseconds and all other frequency outputs will have a 10- to 90-percent rise and fall time of no greater than 500 nanoseconds.

c. All frequency outputs will have a duty cycle of 50±1.0 percent.

d. All frequency outputs will have an overshoot of no greater than 10 percent.

e. All frequency outputs will be at the correct frequency.

2. Verification will be made that without the 1024-kc input present and with all outputs terminated in 100-ohm resistive loads the requirements of test 1 will be satisfied.

9.3.2.2.13.2 System Test. Proper operation of the central timing equipment in conjunction with the other equipment in the communications system will be verified by tests, as in paragraph 9.3.2.2.13.1, that will be performed on all outputs of the central timing equipment that are utilized by communications equipment, and those pieces of equipment will be monitored to verify the compatibility of the central timing equipment with the rest of the communications system.

9.3.2.2.14 Television Equipment.

9.3.2.2.14.1 Equipment Test. Proper operation of the television equipment will be verified by the following test. The TV display of the reduced frame rate picture will be observed to verify:

1. A horizontal resolution of 250 lines and a vertical resolution of 225 lines

2. A gray-scale rendition of at least 5 gray scales

3. A sensitivity capable of providing the above resolution and gray-scale rendition with incident vidicon target highlight illumination as low as 0.1 foot-candle.

9.3.2.2.14.2 Systems Test. Proper operation of the television equipment in conjunction with the other equipment in the communications system will be verified by observing the resolution and gray-scale rendition as displayed.

9.3.2.3 Antenna Test Program

9.3.2.3.1 VHF/2-KMC Scin Antennas. These antennas will be developed and fabricated at NAA. The development tests will be performed during the evolution of the final design. Antenna patterns will be obtained by using one-third-scale antennas and S/C models, and full-scale antennas. Impedance measurements will be made. Dielectric constant and loss tangent measurements will be made on ablator materials in both charred and uncharred conditions. Exploratory vibration tests will be performed. Tests in the vacuum chamber will be made to determine voltage breakdown characteristics.

9.3.2.3.2 2-KMC high-Gain Antenna Equipment. The following tests will be made on the 2-KMC high-gain antenna equipment at the antenna range before installation on the service module.

1. The electrical bore sight will be measured.

2. The IR sensor alignment will be measured and adjusted to coincide with the antenna RF axis.

3. The antenna servos will be calibrated.

4. Azimuth and elevation pattern cuts will be taken for each of the selectable beam widths.

9.3.2.4 Spacecraft—GOSS Compatibility Tests.

9.3.2.4.1 Spacecraft Communications System—GOSS Compatibility Tests. These tests will be necessary to evaluate mutual compatibility of spacecraft and ground communication systems under simulated operational conditions. The spacecraft-GOSS interface test system (SGITS) facility will be equipped with similar performing systems or duplicates of all GOSS interface systems necessary for this evaluation.

The compatibility tests will be conducted with the spacecraft equipment performing its specified function through an RF link tied to the SGITS facility (GOSS functional equipment). The RF link will alter the spacecraft signals so that they will appear to have originated from various positions in space. The signal carrier frequencies, stabilities, power modulation index, threshold and signal margins and intermodulation products will be measured and analyzed for the various communications modes and at signal levels corresponding with simulated space positions.

Communications subsystem tests will be performed to isolate design deficiencies of the various subsystems and to establish their performance capabilities. The primary objectives are to identify marginal performance of specific subsystems, to avoid degradation of performance due to interface mismatch, and to establish quantitatively the design performance capability of each subsystem when properly integrated into the over-all system.

9.3.2.4.2 Feasibility Tests of System and Techniques. These tests will verify the feasibility and performance of modifications to the over-all communications system, as well as individual units of the system under simulated constraints of the mission upon the RF link. The general philosophy will be to seek the simplest possible solution to the problems of incompatibility utilizing, where possible, corrections involving adjustments such as changes in levels or frequencies, rather than redesign of equipment. Results of these tests will be particularly valuable backup data for proposing improvements in the spacecraft-GOSS communications link.

When redesign of the system is required, breadboards of the modifications will be fabricated and tested to verify soundness of ideas, feasibility and optimization of techniques and equipment, conformity of system operation with system philosophy, and optimized formats of information codes. These tests will be performed primarily with the SGITS S/C console.

9.3.2.4.3 Evaluation Tests. Initial spacecraft-GOSS system evaluation tests to ensure optimum spacecraft-GOSS system performance will be conducted with breadboards of modifications that have been proved feasible for the Apollo mission. For further refinement, these tests will be accomplished in conjunction with the house spacecraft test program and will be evaluated for optimization in the actual spacecraft system configuration. Results of these evaluation tests then will be used to recommend that these modifications be incorporated or deleted from the spacecraft communications system.

9.3.3 Equipment

S&ID will provide or procure the use of the following equipment.

RFI shield room
Antenna pattern range
Laboratory test equipment and recorders
Engineering spacecraft simulator
Spacecraft mock-ups
Communications system breadboard

[redacted]

9.3.3.1 Equipment Required (GOSS Only)

The equipment needed to perform all of the feasibility, compatibility, and system evaluation tests will consist of a phase-lock receiver system; telemetry receivers; high- and low-data rate recorders; HF, VHF, and signal generators and receivers; C-band pulse generators; C-band signal generators; frequency standards, synthesizers; noise generators; pseudo-random noise generator and correlator; and, in general, all equipment that should go into a GOSS station, except the data processing systems, antenna systems, and computer.

This equipment will be connected together in the GOSS configurations for all of the tests.

The data ground station, located in Building 6, will support the tests by processing the data, where required.

9.3.4 Facilities

S&ID will provide and use the following facilities at Downey.

Bench maintenance equipment
Data acquisition and recording station
Spacecraft-GOSS interface test system (SGITS) facility

The SGITS facility will be located at S&ID in Downey. The facility will occupy a 30 by 30 foot area and will be composed of an operation area and a testing area.

9.3.5 Test Schedule

The S&ID communications system and the spacecraft-GOSS compatibility test schedules are shown in Figure 9-5.

9.4 INSTRUMENTATION SYSTEM TESTS

9.4.1 Objective

The objective of the instrumentation system tests will be to ensure that the system will furnish the required information in the specified form, from the source to the designated utilization points, under the specified environmental conditions without interfering with the designed function of other systems.

[redacted]

9.4.2 Test Plan

The test program consists of evaluation tests of representative transducers from potential sources to assist in final determination of the procurement source for each type of transducer, qualification tests, subsystem tests, and combined system tests. The items to be tested include sensors, associated equipment, subsystems, and special instrumentation such as optical, scientific, and biomedical.

9.4.2.1 Qualification Tests

9.4.2.1.1 Objective. The objective of qualification tests will be to ensure that the system components provided by the vendors will perform according to the specifications under defined environmental conditions and with sustained reliability over a delineated period of time.

9.4.2.1.2 Test Plan. The various system components will be tested for performance characteristics, such as linearity, hysteresis, stability, repeatability, and output level. During the tests, the components will be subjected to varying environmental conditions of vibration, shock, acceleration, acoustics, temperature, and radiation. Reliability will be determined by monitoring the component's output over an extended period of operation.

9.4.2.1.3 Program Requirements. Test articles will include such components as pressure transducers, temperature transducers, flow meters, quantitative transducers, acoustic transducers, vibration accelerometers, attitude gyros, rate gyros, signal conditioners, and ablation transducers. Data will be recorded by oscillographs, oscilloscope cameras, tape recorders, and other data-logging devices.

9.4.2.1.4 Equipment. Vacuum chambers, pressure chambers, ovens, etc., will be used to simulate the desired environmental conditions for test.

9.4.2.1.5 Facilities. The test facility will consist of a complete evaluation laboratory equipped with environmental chambers, measurement standards, recording equipment, and typical test equipment.

9.4.2.1.6 Test Schedules. Test schedules will vary for each component, dependent upon type, number of each type being tested, and the test vehicle for which it is intended.

9.4.2.2 Acceptance Tests

9.4.2.2.1 Objective. The objective of the acceptance tests will be to ensure that each component item received is in satisfactory operating condition and is capable of performance in accordance with the specifications.

[redacted]

9.4.2.2.2 Test Plan. Each component item received will be inspected initially to ensure good mechanical condition, correct dimensions, proper identification marking, etc. Following the receiving inspection, the individual component item will be subjected to an operational checkout that tests the performance characteristics of the item under limited environmental conditions indicated for the qualifying inspection. The preinstallation test will be performed immediately prior to delivery of the component item to manufacturing for system installation in a test vehicle. The preinstallation test essentially will be the same as the operational checkout. It will be performed to ensure that no degradation in performance has occurred during the shelf-time period of the component item.

9.4.2.2.3 Program Requirements. The program requirements will be the same as those for the qualification tests (paragraph 9.4.2.1.3).

9.4.2.2.4 Equipment. The equipment will be the same as that to be used for the qualification tests (paragraph 9.4.2.1.4).

9.4.2.2.5 Facilities. The test facility will consist of a complete evaluation laboratory equipped with environmental chambers, measurement standards, recording equipment, and typical test equipment. The test facility will be located at S&ID, Downey, California.

9.4.2.2.6 Test Schedule. Test start dates will occur toward the end of the manufacturing phase for each test vehicle involved.

9.4.2.3 Subsystem Tests

9.4.2.3.1 Objective. The objective of subsystem tests will be to determine the interaction of the components when they are functioning as part of the complete subsystem.

9.4.2.3.2 Test Program. Subsystem tests will be conducted in boilerplates or airframes, either during the manufacturing phase or after its completion. Input and output readings will be made at the appropriate check points to ensure that all instrumentation components in the system are functioning according to the design specifications. Malfunction, when occurring, will be investigated thoroughly. If the malfunction is caused by component interaction, the component that causes the malfunction may be redesigned.

9.4.2.3.2.1 Subsystem Tests. Subsystem tests to determine the compatibility of the components with other spacecraft subsystems, especially the electrical type, will be performed under operational conditions without simulated environment in B-14. The effects of an acoustical and vibration

[redacted]

environment will be determined during subsystem tests conducted on Airframe 001, Test Fixture 2, and Airframe 006. The effects of the temperature and vacuum environments will be determined during subsystem tests conducted on Airframe 008.

9.4.2.3.2.2 Program Requirements. The test article will be the complete subsystem. Recording methods and recording equipment will be the same as the equipment to be used in the qualification tests (paragraph 9.4.2.1.3).

9.4.2.3.3 Equipment. Equipment to produce simulated environmental conditions will consist of a thermal vacuum space simulator for AFRM 008, an acoustic and vibration environment for AFRM 006, service propulsion and reaction control propulsion systems for AFRM 001, and a service propulsion system for Test Fixture 2.

9.4.2.3.4 Facilities. Test facilities for installation of the instrumentation subsystem will be the designated test vehicles. The test locations will be the Apollo Propulsion Systems Development facility WSMR for Airframe 001 and Test Fixture 2; the in-house Spacecraft 1 manufacturing area at NAA, S&ID, Downey, California, for Boilerplate 14, acoustic and vibration laboratory at NAA, S&ID, Downey, for Airframe 006; thermal vacuum space simulator at AEDC, Tullahoma, Tennessee, or at MSC, Houston, Texas, for Airframe 008; and the respective manufacturing and test sites for each vehicle for Airframe 009 and Airframe 011. Test facilities may be fixed (such as test stands), portable (such as individual items of test equipment), or mobile (such as instrumentation trailers).

9.4.2.3.5 Test Schedule. Test start dates will occur toward the end of the manufacturing phase for each test vehicle involved.

9.4.2.4 Integrated System Tests

9.4.2.4.1 Objective. The objective of combined system tests will be to determine the interaction of subsystems when they are functioning as a part of the complete system.

9.4.2.4.2 Test Program. Integrated system tests will be conducted in boilerplates or airframes upon completion of the manufacturing phase. Input and output readings will be made at the appropriate check points to ensure that all subsystems are functioning according to the design specifications. Malfunction, when occurring, will be thoroughly investigated. If the malfunction is determined to be caused by subsystem interaction, the subsystem that caused the malfunction may be redesigned.

[redacted]

9.4.2.4.3 Program Requirements. The test article will be the complete integrated system. Recording methods and recording equipment will be the same as those to be used in the qualification tests (paragraph 9.4.2.1.3).

9.4.2.4.4 Equipment. Equipment will be the same as the equipment to to used for the qualification tests (paragraph 9.4.2.1.4), less environmental chambers.

9.4.2.4.5 Facilities. Facilities will be the same as the facilities to be used for the subsystem tests (paragraph 9.4.2.3.5).

9.4.2.4.6 Test Schedule. The integrated system test schedule is shown in Figure 9-5.

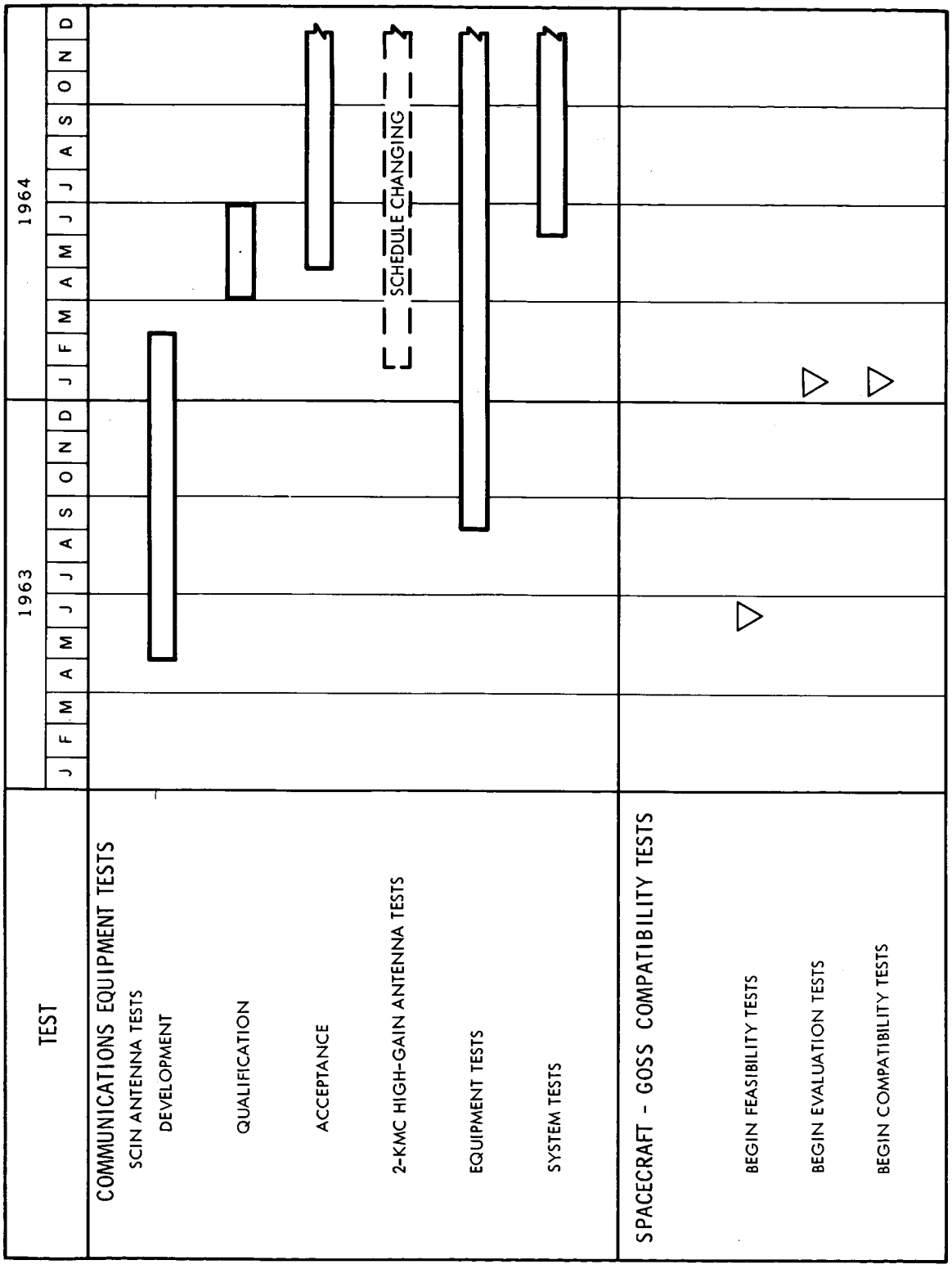

Figure 9-5. S&ID Communications System and Spacecraft—GOSS Compatibility Test Schedules

10.0 LIFE SYSTEMS

10.1 SCOPE

This section comprises an outline of the life systems development design evaluation and qualification tests to be accomplished during Apollo system development, qualification, and flight test. The intent of this test plan is to specify test requirements for determination of equipment, facilities, and test scheduling and for integration of life systems test requirements into the over-all test program. Detailed test plans will be provided by life systems, as required, to implement the general test plan contained in this document.

The life systems test plan is divided into two major program areas as follows:

1. Crew systems and equipment test program (engineering evaluation and qualification of Apollo system man-machine, human engineering, and environmental interfaces) (Refer to paragraph 10.2.)

2. Crew engineering and environmental simulation test program (evaluation and qualification of the interactive effects of human performance and systems performance) (See paragraph 10.3.)

In addition, life systems developmental test requirements concerning flight-drop and launch tests will be integrated into the multiple systems test programs for development and design proofing.

10.2 CREW SYSTEMS AND EQUIPMENT TEST PROGRAM

Crew systems and equipment tests will be conducted to evaluate crew equipment, spacecraft systems, and related GSE systems man-machine, human engineering, and environmental interface designs. Initial tests will be conducted to evaluate life systems design concepts and functions and to obtain an early insight into problem areas or deficiencies of the man-machine relationships. Design evaluation tests will begin prior to the preliminary drawing release. Testing will progress from breadboard equipment models installed in mock-ups and simulators and will continue throughout design development in the house spacecraft, during major ground tests, boilerplate tests, and the flight-test programs. To facilitate identification of specific

test requirements, the life systems design evaluation program is divided into equipment and systems test categories: crew equipment tests and spacecraft (crew) systems interface tests.

10.2.1 Crew Equipment Tests

The crew equipment provisions that are to be evaluated will include the following:

Crew support (couch and attenuation) system
Restraint system
Space suit assembly
Crew accessories
Survival equipment
Biomedical equipment and provisions

10.2.1.1 Crew Support (Couch and Shock Attenuation) Systems Tests

Crew support systems tests will be conducted in two concurrent test areas consisting of (1) human engineering tests and (2) dynamic tests.

10.2.1.1.1 Human Engineering Tests.

10.2.1.1.1.1 Objectives. Tests will be conducted to verify the design of the crew couch suspension and restraint system for conformance with crew system human engineering design criteria (S&ID and NASA specifications) and to verify integration and interface compatibility of associated crew equipment items.

10.2.1.1.1.2 Test Requirements.

1. Anthropometrics. Verify dimension, with weight and center-of-gravity locations, for all major components of the couch. Verify couch contour and design for compatibility and fit with human anatomy. Determine and evaluate visual and functional reach envelopes with human subject (10 through 90 percentile) in relation to couch and restraint system design. Obtain camera coverage for documentation.

2. Crew Interchangeability. Evaluate couch and restraint system design for crew interchangeability. Conduct tests with appropriate combinations of human subjects, 10 through 90 percentile. Evaluate couch and restraint systems attachments and adjustments for ease of operation. Obtain motion picture and time-history data for evaluation and permanent record.

[redacted]

3. Attachment, Adjustment, and Release. Conduct tests with human subjects (10 through 90 percentile) to functionally evaluate the combined couch and restraint system for attachment, adjustment, and release capabilities. Record deficiencies or problems encountered for design improvement. Obtain time-motion picture coverage and time-history data for evaluation and permanent record as required.

4. System Compatibility. Verify compatibility of crew couch and restraint system with pressure garment assembly, personal clothing and accessories, and any other related equipment or couch attaching structure. Conduct functional, operational tests for evaluation of systems interaction (interference, accessibility, maintainability, and characteristic performance). Obtain documentary photographs for analysis and record, as required.

5. Comfort. Evaluate human comfort tolerance levels for full body and head support. Evaluate all couch and body positions. Conduct tests within the duration and environmental parameters typical for the Apollo missions. Determine any deficiencies or problems regarding degree of comfort, localized high-pressure bearing locations, and associated time factors.

6. Crew Capability. Verify design for crew capability of ingress and egress into crew couch and restraint system. Conduct tests for all conditions of ingress and egress, including prelaunch, in-flight, zero-gravity, and postlanding emergency egress. Recapitulate action and time histories of the tests with lapsed-time camera coverage.

10.2.1.1.1.3 Equipment Requirements. Human engineering tests of the couch suspension and restraint systems will require human test subjects equipped with pressure suits and related items of personal equipment. The test subjects' performances will be recorded by stop watch, time-motion camera, and still photography. Provisions must be made for pressurizing and venting the pressure suits. Intercommunication between test subjects and test operations personnel will be required.

10.2.1.1.1.4 Facilities. Developmental and engineering design tests will be conducted at Downey, using Apollo development mock-ups 2, 12, and 18 and house spacecraft 1. Qualification tests will be conducted in the house spacecraft, Airframe 006, and in conjunction with the environmental proof test program, Airframe 008.

[redacted]

[redacted]

10.2.1.1.1.5 Test Schedule. The test schedule for the crew support system test program is shown in Figure 10-1.

10.2.1.1.2 Dynamic Tests.

10.2.1.1.2.1 Objectives. Tests will be conducted to evaluate the crew couch, suspension, and restraint system full body and head support design for all Apollo nominal and emergency acceleration impact vibration and acoustical profiles. Evaluate histories of accelerations, impact, and vibration loads imposed on crew members and critical structure of the couch.

10.2.1.1.2.2 Test Requirements. Tests will be conducted as follows:

1. Land and Water Impact Tests. Crew support (couch and shock attenuation) system drop tests will verify that Apollo crew members will not be subjected to impact acceleration loads in excess of those specified in the Apollo Statement of Work, Part III, Figures 12 and 13.

   Anthropomorphic dummies (10, 50, and 90 percentile) will be secured in the support system couches with the restraint systems. Associated items of crew equipment will be included in the tests.

   The weight and center of gravity for each couch-dummy combination will be ascertained prior to each test to assist in evaluating impact acceleration loads imposed on the attenuation devices and to obtain data for center-of-gravity management.

   Tests will be conducted with various combinations of dummy sizes and seat arrangements including loadings of less than three crewmen to cover the cases of one or two crewmen lost during lunar operations. The command module will be dropped with various combinations of vertical and horizontal velocities and various command module orientations.

   Tri-axial accelerometers will be installed in the dummy's chest, in the head (SCIP instrumentation), on the couch, and on the command module floor structure. Couch measurements will be used for appraising Apollo capability in meeting NASA defined human tolerance limits. The time histories of accelerations will be recorded. High-speed motion picture coverage will record the dynamic action for analysis and permanent record. Boilerplates 1 and 2 and Airframe 005 will be utilized for the land and water impact tests. These tests will be performed in conjunction with, and as part of, the landing impact and stability structural test program (Section 12. 0).

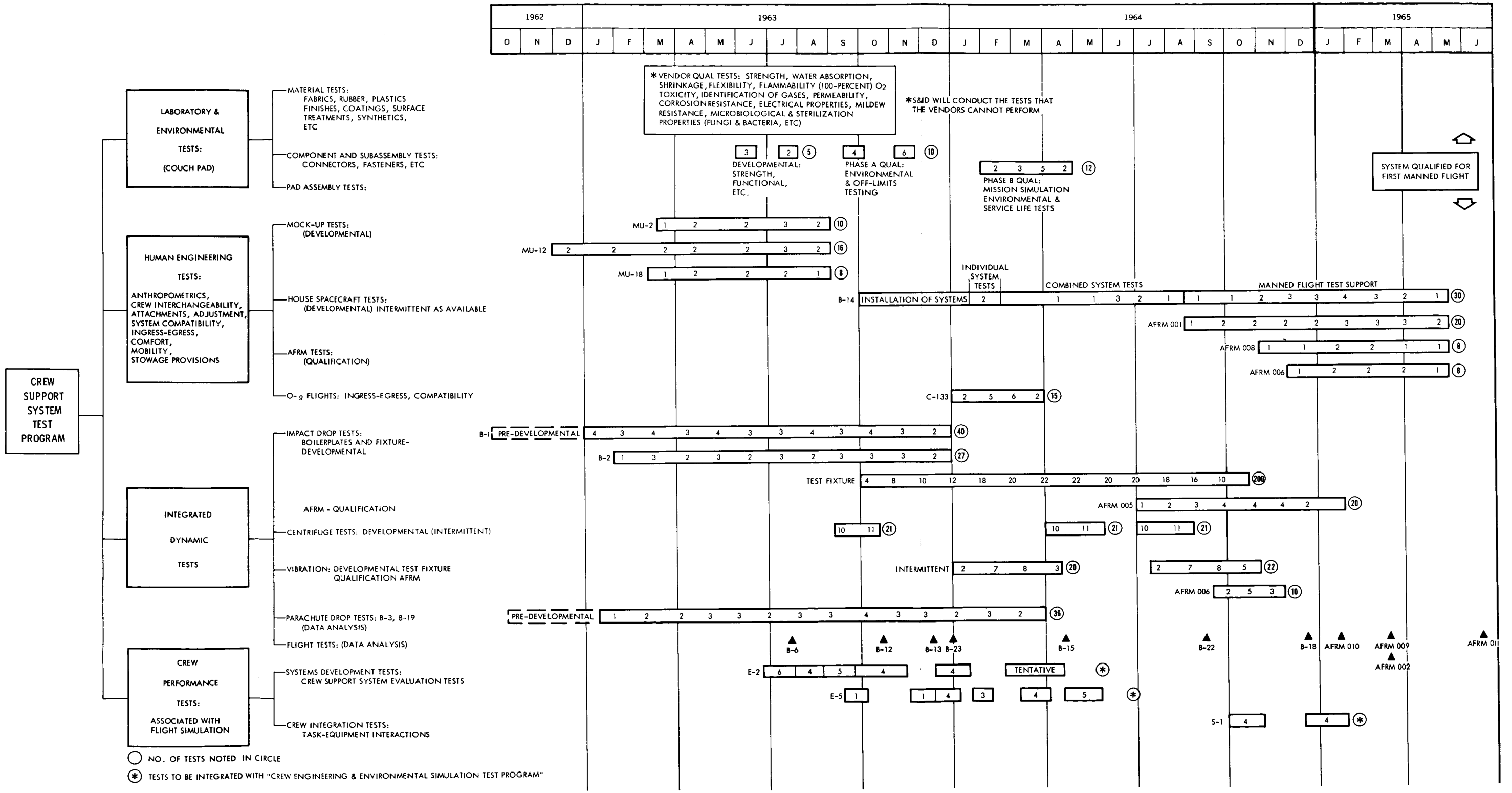

Figure 10-1. Systems Approach - Crew Support System Test Program

2. Vibration Tests. Crew support system will be tested to verify the following:

   a. That the vibrational response of the crew support system, mounted on the shock mitigation suspension system, does not exceed the designated vibration limits (specified in SID 62-700-2, Part III, Figure 14) when the system is subjected to vibrational parameters anticipated for the command module during mission phasing in which there is high vibration (such as launch, booster separation, command module and service module separation, and reentry)

   b. That the characteristic vibrational environment for the crew does not exceed the physiological tolerance limits and the human psychophysical factors necessary to perform operational and task requirements for all phases of the Apollo mission. These performance determinations will be carried out on all crew-operated systems that are used during vibration periods. The tests are described in paragraph 10.3, Crew Engineering and Environmental Simulation Test Program.

Anthropomorphic dummies will be secured in the couch with the restraint system for proof loading prior to testing with subjects. The couch and shock attenuation system will be mounted on the vibration table in a test fixture representative of the command module interior installation. Tri-axial accelerometers will also be mounted on the couch and on the vibration table. The time histories of all accelerometers will be recorded simultaneously. The general vibration test procedure specified in MIL-E-5272C will be followed, except that the vibrational parameters (frequency, amplitude, g's, and time duration) will be commensurate with the anticipated level for a typical Apollo mission.

Performance tests will be performed with human subjects (10 through 90 percentiles) equipped with full-pressure suits to verify the requirements of (b) above and to obtain comparative data for possible correlation during dummy runs on emergency profiles considered unsafe for human exposure. Instrumentation and sensors will be provided to monitor human psychophysical factors and physiological response.

[redacted]

The human subjects must be able to monitor displays and perform tasks satisfactorily during representative vibrations to assure the safety of the Apollo mission. (See paragraph 10.3.) These tests will be repeated if, after early mission launches, the vibrational response of the command module is more severe than the tested response.

The qualification vibration test program will be conducted in conjunction with, and as part of, the Airframe 006 vibration part of the environmental proof test program (see Volume V, Section 5.0).

3. Centrifuge Tests. The crew support (couch, suspension, and restraint) system will be fixture mounted and tested in a centrifuge to verify that the sustained acceleration profiles imposed on the crew members do not exceed the physiological tolerance limits and human psychophysical factors necessary to perform operational task requirements necessary for all phases of the Apollo mission.

The tests will be conducted with human subjects (10 through 90 percentile) to verify the preceding requirement. Prior to the conduct of tests with human subjects, the crew support system will be proof-tested to a sustained acceleration of 1.5 times that of the mission profile. The subjects will be equipped with pressure suits, pressurized and unpressurized, and will perform simulated duty tasks while being subjected to sustained acceleration profiles representative of the various phases of the Apollo mission.

A couch and shock attenuation system will be mounted on a centrifuge gondola representative of a portion of the Apollo cabin interior configuration. Biomedical instrumentation will be mounted on the test subject. Force-link sensors will be installed on the restraint system. Time histories of the acceleration and forces will be recorded as the crew support system is subjected to various sustained acceleration profiles of the Apollo mission.

Complete data will be collected of crew abilities in the manual mode during acceleration. Two television cameras will be located to monitor continuously the couch and subject response. Equipment will be provided for pressurizing the pressurized suits. Boilerplate crew couches will be used until spacecraft items are available. These tests will be conducted concurrently with, and as part of, the boost and reentry phases of the simulation centrifuge program. (Refer to paragraph 10.3.)

4. Flight Drop Tests. Acceleration forces applied to the crew support system will be evaluated during the flight drop-test program to verify that the recovery parachute opening loads do not subject the crew personnel to shock acceleration forces in excess of those specified in the Apollo Statement of Work, Part III, Figures 12 and 13. Deceleration loads are limited for nominal and emergency conditions and should be investigated when the attitude and center of gravity of the command module are in an adverse relationship with the direction of applied parachute opening forces. Data obtained during the earth landing system test program (see Section 4.0) will be applied for evaluation of the applied parachute opening shock loads.

5. Launch Tests (Abort and Orbital). The crew support system will be evaluated on the basis of data obtained during the flight test program to verify that the acceleration and vibration loads imposed on crew personnel do not exceed those specified in the Apollo Statement of Work, Part III, Figures 1 through 13. Data for the above evaluation will be obtained from instrumentation provided during conduct of the following tests:

   Pad abort—BP-6, Airframe 010 (BP-23 backup)
   Maximum q abort—BP-12, Airframe 002 (BP-23 backup)
   Very high-altitude abort—BP-22
   Unmanned qualification flight—Airframe 009
   First manned orbital—Airframe 011.

10.2.1.1.3 Equipment Requirements. Instrumented anthropomorphic dummies will be required for the land and water impact test programs. Human subjects with pressure suits will be required for the centrifuge and also for the vibration test program.

Instrumentation requirements for monitoring the earth landing system test program are specified in Section 4.0.

Instrumentation requirements for monitoring the launch test program are specified in Volume V, Multiple Systems Tests.

10.2.1.1.4 Facilities. Facilities requirements are as follows:

1. Land and Water Impact Tests. See Landing Impact and Flotation Tests, Section 12.0.

2. Vibration Tests. See Crew Couch and Shock Attenuation Absorption Tests, Section 13.0.

[redacted]

3. Centrifuge Tests. See Figure 10-1.

4. Flight Drop Tests. See Earth Landing System Tests, Section 4.0.

5. Launch Tests. See Volume V, Multiple Systems Tests.

10.2.1.1.5 Test Schedules. For the over-all test schedule, see Figure 10-1. For the detailed schedule, refer to the following:

1. Land and Water Impact Tests. See Section 12.0.

2. Vibration Tests. See Section 13.0.

3. Centrifuge Tests. See Figure 10-1.

4. Flight Drop Tests. See Section 4.0.

5. Launch Tests. See Volume V, Multiple Systems Tests.

10.2.1.2 Restraint System Tests

10.2.1.2.1 Objectives. The objectives of the restraint system tests will be to verify the design of the restraint harness as follows:

1. Each crew support system will use a restraint harness to protect the Apollo crew members from acceleration and vibration loads imposed during Apollo nominal, nonstressed, and emergency conditions. The restraint system will also have retention capabilities to support the crew in a manner which will enable or assist them in performing their required tasks during these stressed and emergency conditions.

2. The design of the restraint system will be compatible with the design of the crew couch, pressure suit, and other adjacent or related equipment.

10.2.1.2.2 Test Requirements.

10.2.1.2.2.1 Component Materials Tests.

1. Environmental Tests. One complete restraint system will be subjected to the high- and low-temperature, sunshine, humidity, fungus, hard vacuum, and radiation tests in accordance with the requirements of MIL-E-5272C. Levels of environments applied will be those commensurate with the anticipated maximum level for the Apollo mission. (Refer to Volume III, Section 4.0.)

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2. Static Structural Tests. Three complete restraint assemblies will be statically tested to determine their structural capabilities. The harness will be assembled and installed on the crew support couch for these tests. Loads will be transmitted to the harness assembly through an appropriate structure or anthropomorphic dummies.

The magnitude of the loads will be the dynamic g-load limits specified in the Apollo Statement of Work multiplied by a 1.5 safety factor. The loads will be based on the total weight of a 90-percentile dummy equipped with pressure suit and other auxiliary equipment.

The direction of the loads will be appropriately applied to the restraint system in the direction of each of the three major command module axes (three tests). In addition, combined loads will be applied in a direction inclined 45 degrees to the X axis for the XZ plane and repeated for XY plane (one test for each of the four possible directions).

At the conclusion of these proof-load tests, one test will be conducted to determine the ultimate strength of the restraint system in the direction of the most critical load.

These tests may be conducted in conjunction with the crew support (couch, suspension) system tests. (See Section 13.0.)

10.2.1.2.2.2 Human Engineering Tests. Human engineering design evaluation tests will be conducted concurrently with, and as part of, the human engineering test program for the crew support system. (See paragraph 10.2.1.1.1.)

10.2.1.2.2.3 Dynamic Tests. The characteristic performance capabilities of the restraint system during nominal, nonstressed, and emergency loading conditions will be evaluated concurrently with, and as part of, the dynamic test program for the crew support system. (See paragraph 10.2.1.1.2.)

10.2.1.2.3 Equipment and Facilities. Materials tests and static structural tests will be conducted at the S&ID Engineering Development Laboratory facilities. The human engineering and dynamic tests of the restraint system will be conducted as part of the crew support system test program described in paragraph 10.2.1.1.

10.2.1.2.4 Test Schedule. See the crew support system test schedule in Figure 10-2.

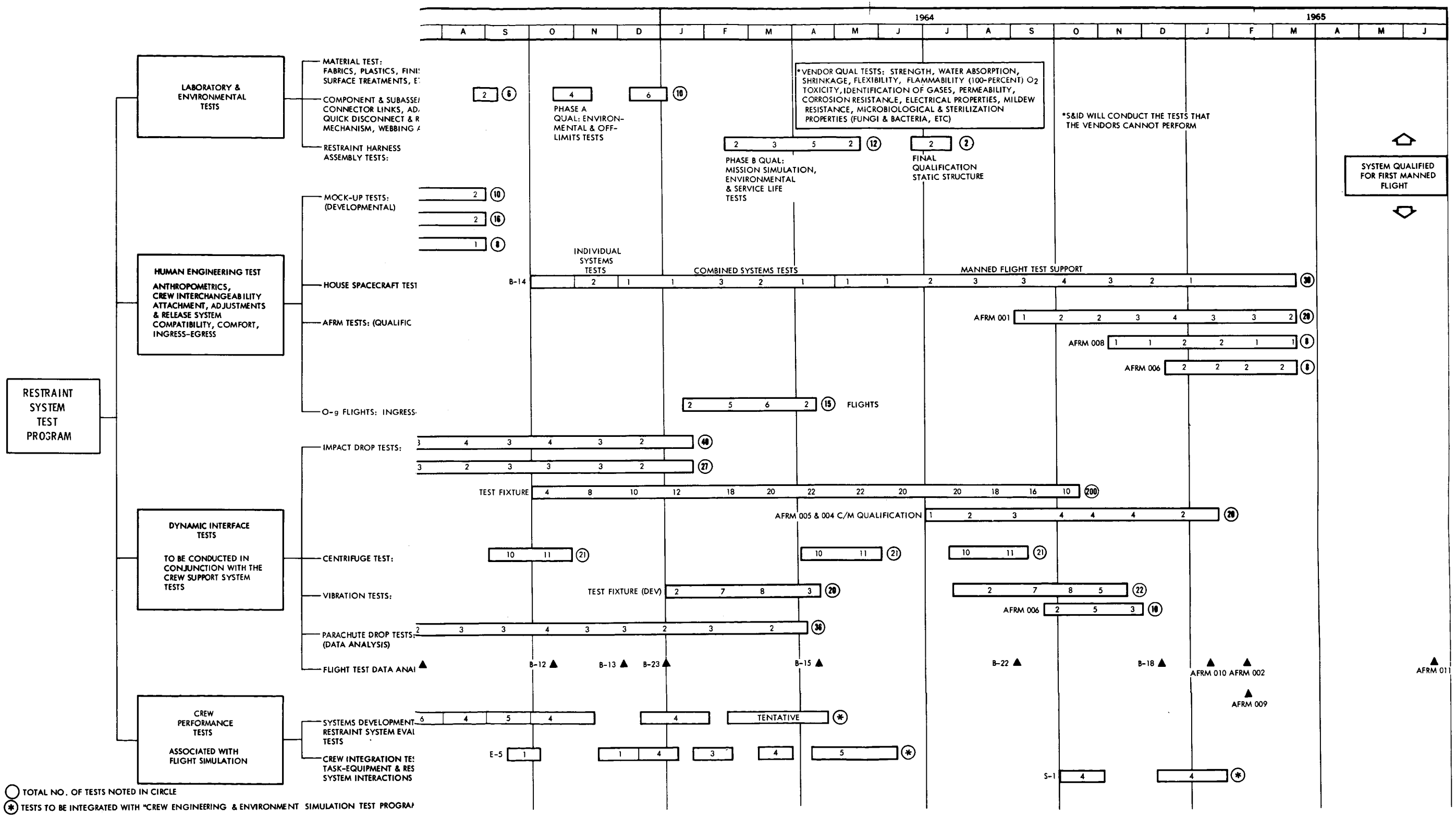

Figure 10-2. Systems Approach - Crew Restraint System Test Program

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10.2.1.3 Space Suit Assembly Interface Tests

10.2.1.3.1 Test Requirements.

10.2.1.3.1.1 Subcontractor Tests. Developmental tests for the space suit assembly will be conducted by the NASA associate contractor as directed by the NASA. Life systems will monitor major test milestones and will coordinate those tests which reflect interface with the Apollo vehicle.

10.2.1.3.1.2 Apollo Integration Tests. S&ID is charged with integration of the space-suit assembly with the vehicle and will conduct a continuous program leading from early prototypes to final qualification and first-flight assemblies. (Refer to SID 62-1003, NASA Furnished Crew Equipment Interface Requirements Specification.)

10.2.1.3.1.2.1 Human Engineering Tests.

1. Dimension and tariff of suit components will be verified against the actual anthropometric range of Apollo personnel. This includes the space suit assembly and special overgarments in conjunction with the crew couch and restraint systems. Both pressurized and unpressurized determinations will be made.

2. Tests will be conducted to determine pressurized and unpressurized pressure garment assembly kinetics for interface with the cabin interior configuration. Maximum reach, functional reach, and visual envelopes will be evaluated for orbital, reentry, and emergency acceleration profiles, as well as donning and doffing time and space requirements with relation to the 5-minute flood flow duration.

3. Comfort will be empirically evaluated in terms of the mission environmental parameter duration and limitations noted for subsequent design compensation. This investigation will be concurrent with the crew support system test program. (Refer to paragraph 10.2.1.1.) The influence of acceleration, vibration, impact, acoustical, and thermal envelopes predicted for the Apollo mission represent primary influences which will be considered with reference to the space suit assembly and will complement the human engineering portions of the study.

10.2.1.3.1.2.2 System Compatibility Tests. Human testing will qualitatively evaluate the interactions of the space suit assembly and environmental control system with the crew couch and restraint system interfaces. Additional performance tests will evaluate biosensor compatibility, personal communications interface, stowage provisions for

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[redacted]

the portable life support system (PLSS), operation, and storage provisions for the space suit assembly. Such testing will be reflected in essentially all of the crew engineering and environmental simulation program and will be integrated with the ECS space suit compatibility tests during the ECS breadboard manned test program

10.2.1.3.2 Equipment and Facilities. The space suit assembly is a basic requirement for virtually all phases of the life systems human engineering, crew performance, and flight simulation programs. Equipment and facilities necessary for the over-all program are reflected in Figure 10-3. Human subjects, anthropometric dummies, suit support consoles, and physiological instrumentation will be required in conjunction with medical support in order to effect the scope of investigation.

10.2.1.3.3 Test Schedule. The test schedule and chronology of the space suit assembly interface tests is shown in Figure 10-3.

10.2.1.4 Crew Accessories Verification Tests.

10.2.1.4.1 Objectives. Life systems testing will verify the interface of all crew accessories equipment in conformance with Apollo design criteria reflected in SID 62-1003.

Items to be tested include the following:

1. Crew Accessories

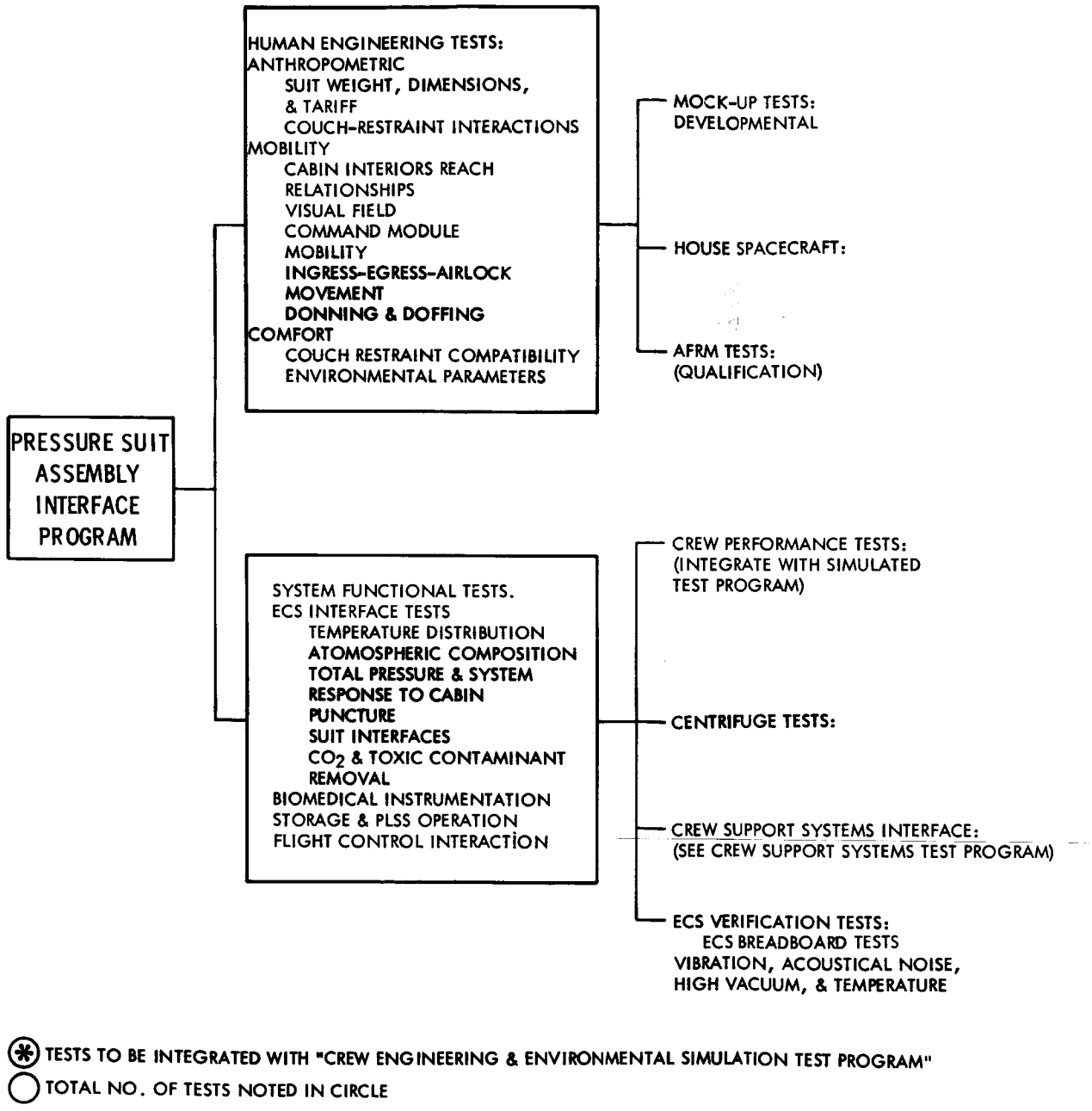
   a. Map and manual set
   b. Logbook
   c. Lapboard
   d. In-flight maintenance tool set
   e. Hatch egress accessories

2. Crewman Equipment

   a. In-flight maintenance belt assembly
   b. Personal shoe strap assembly

3. Personal Hygiene Equipment

   a. Cleaning pad set
   b. Ingestible dentifrice
   c. Shaver
   d. Deodorant pad set
   e. Facial toilet tissue set
   f. Radiation osimeters (GFE)



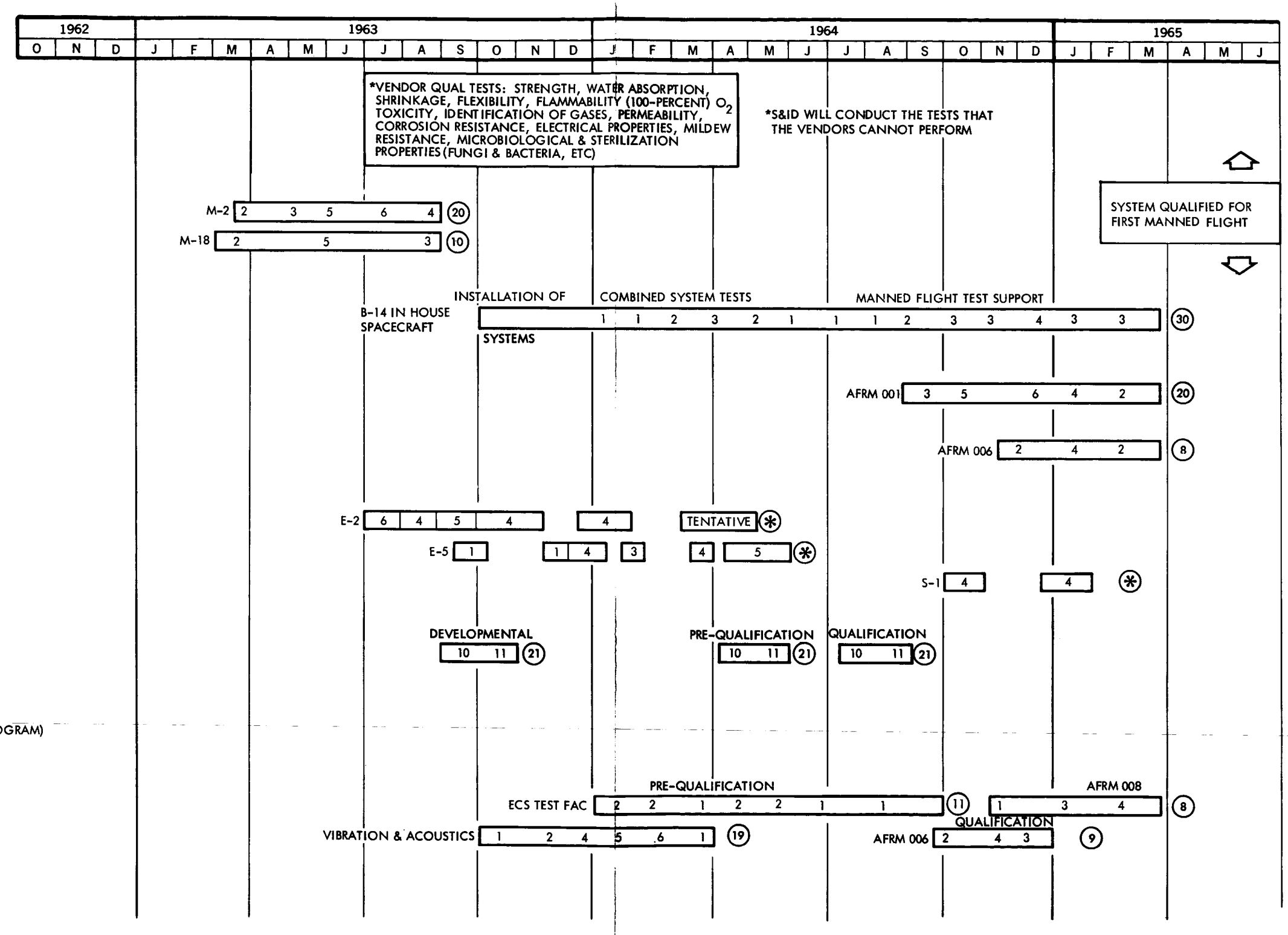


Figure 10-3. Systems Approach - Pressure Suit Assembly Interface Test Program

4. Personal Communications

   a. Personal communications assembly (headset, microphone, and constant wear hat)
   b. Crewman transceiver
   c. Personal communications base station

10.2.1.4.2 Rest Requirements.

10.2.1.4.2.1 Laboratory Testing. Laboratory testing will be performed in order to qualify CFE personal hygiene and other items of crew accessories terms of material specifications. Chemical and physical properties that may create fire hazards or cabin contamination will be evaluated on a concurrent basis to assure compatibility with the command module environment.

10.2.1.4.2.2 Human Engineering Tests. Verification of interfaces with supporting command module systems, such as storage facilities, electrical power, environmental control system, and pressure garment assembly will be accomplished.

Performance envelopes for utilization of crew accessories are to be included on a concurrent basis with this level of investigation. These tests will be accomplished concurrently with, and as part of, the crew engineering and environmental simulation program (refer to paragraph 10.3) and will be integrated with the ECS breadboard test program.

10.2.1.4.3 Equipment and Facilities. The crew accessories test program will use test articles and facilities shown in Figure 10-1. Representative investigations include the following:

1. Materials and environmental testing to be performed by the S&ID Engineering Development Laboratories

2. Developmental tests using mock-ups and breadboards installed in engineering mock-ups 2, 12, and 18 and evaluator 5

3. Human engineering evaluations within house spacecraft B-14 and simulators 1 and 2 using spacecraft prototype hardware

4. Qualification tests to require representative space-rated articles and to be conducted in Airframe 006 and in the Downey space chamber test capsule

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The intimate relationships of crew items demand extensive human testing. This would be accomplished through habitability studies scheduled over a continuous period of days in conjunction with appropriate pressure suit assemblies plus biophysical and motion picture instrumentation.

10. 2. 1. 4. 4 Test Schedule. The test schedule for crew accessories is shown in Figure 10-4.

10. 2. 1. 5 Survival Equipment Tests

10. 2. 1. 5. 1 Objectives. Tests will be conducted to verify the design, packaging, and storage of all survival equipment items for conformance with S&ID and NASA design criteria. The operational suitability of survival equipment items will be evaluated and qualified for optimum human utilization and conformance with the Apollo survival mission constraints. Collective kit items to be tested include the following:

One-man life raft (includes dye marker)
Water and container (2. 5 liters)
Astronaut knife
Permutit kit (11 pt)
Three-day food rations
Signal mirror and sunglasses
Needles, sharpening stone, and penknife
Radar reflector
Transceiver, locator beacon, flashing light, and battery
First-aid kit

10. 2. 1. 5. 2 Test Requirements. Survival equipment tests will be conducted as follows:

10. 2. 1. 5. 2. 1 Component Selection and Packaging.

1. Laboratory tests will be conducted to evaluate the chemical and physical interactions of individual survival equipment components with anticipated Apollo environments thermal, atmospheric, etc.

2. Container and components packaging will be evaluated in general accordance with MIL-E-5272C, except that levels of environments applied will be those commensurate with the anticipated maximum levels for the Apollo mission. (Refer to Volume III, Section 4. 0.)

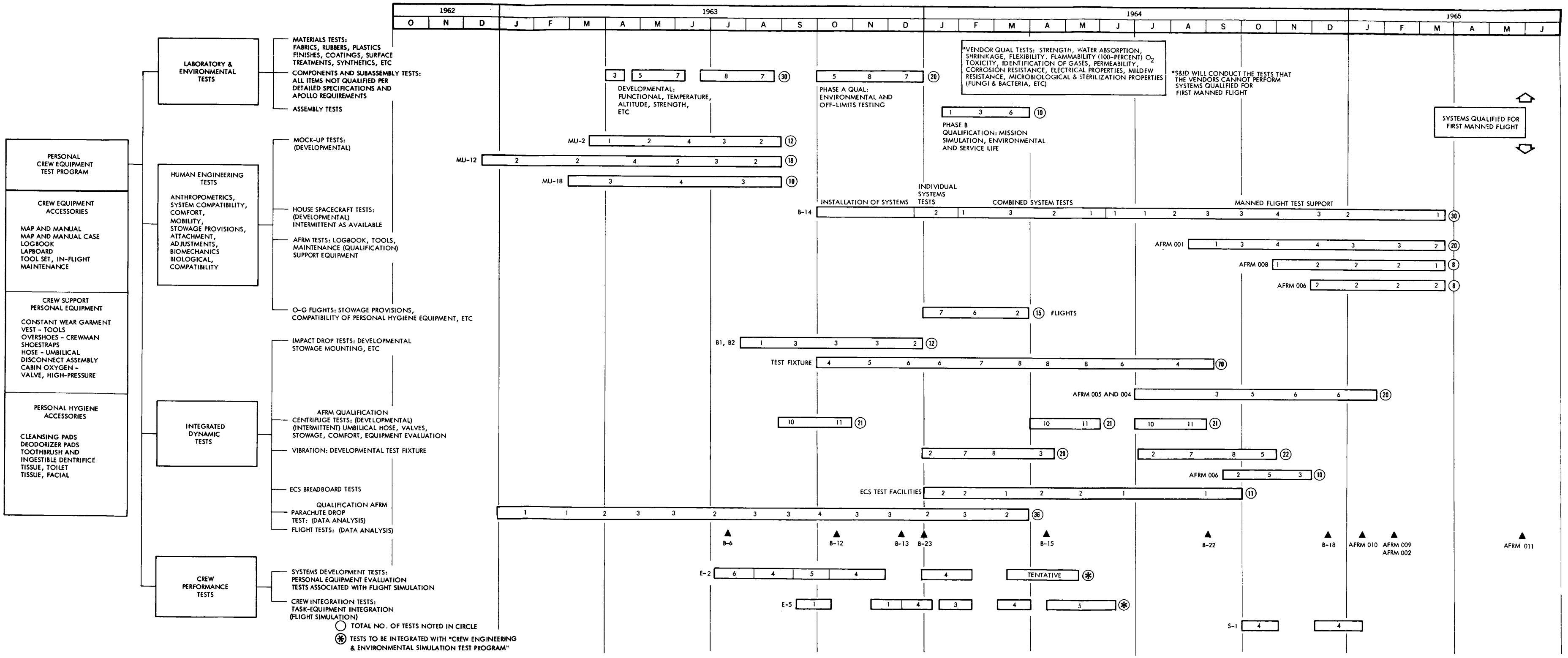

Figure 10-4. Systems Approach - Personal Crew Equipment Test Program

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10.2.1.5.2.2 Systems Integration.

1. Storage provisions will be functionally verified for requirements of the Apollo mission (e.g., sizing, security of attachment, access, etc.).

2. The mobility of crewmen under all conditions of egress, including survival provisions, will be evaluated. Time-motion picture coverage and time histories for all nominal and emergency egress conditions with survival gear will be obtained for analysis and record.

10.2.1.5.2.3 Survival Tests. Crew equipment and components will be verified for functional use in actual and simulated survival environments. A rigorous S&ID-NASA test program will be conducted to test survival performance. Testing will be conducted, as necessary, utilizing Air Force Survival School facilities and environments, such as tropic, arctic, mountain, desert, and water (arctic and tropic) environments.

10.2.1.5.3 Equipment and Facilities. The survival equipment test program will utilize test articles and facilities as shown in Figure 10-5. Specific requirements are as follows:

1. Materials and laboratory tests will be conducted at the S&ID Engineering Development Laboratories.

2. Design developmental tests will utilize equipment mock-ups and breadboards installed in the engineering mock-ups 2, 12, and 18.

3. Systems integration of survival equipment will utilize developmental or first-run equipment articles installed in the house spacecraft B-14.

4. Functional performance tests (developmental and qualification) will be conducted utilizing the B-2 test vehicle for water egress and flotation tests. Air Force Survival School facilities will be utilized, if required.

5. Human test subjects fitted with operational pressure garment assemblies will be required.

6. Time-motion photographic instrumentation will be required.

10.2.1.5.4 Test Schedule. Survival equipment tests will be scheduled within the framework shown in Figure 10-5.

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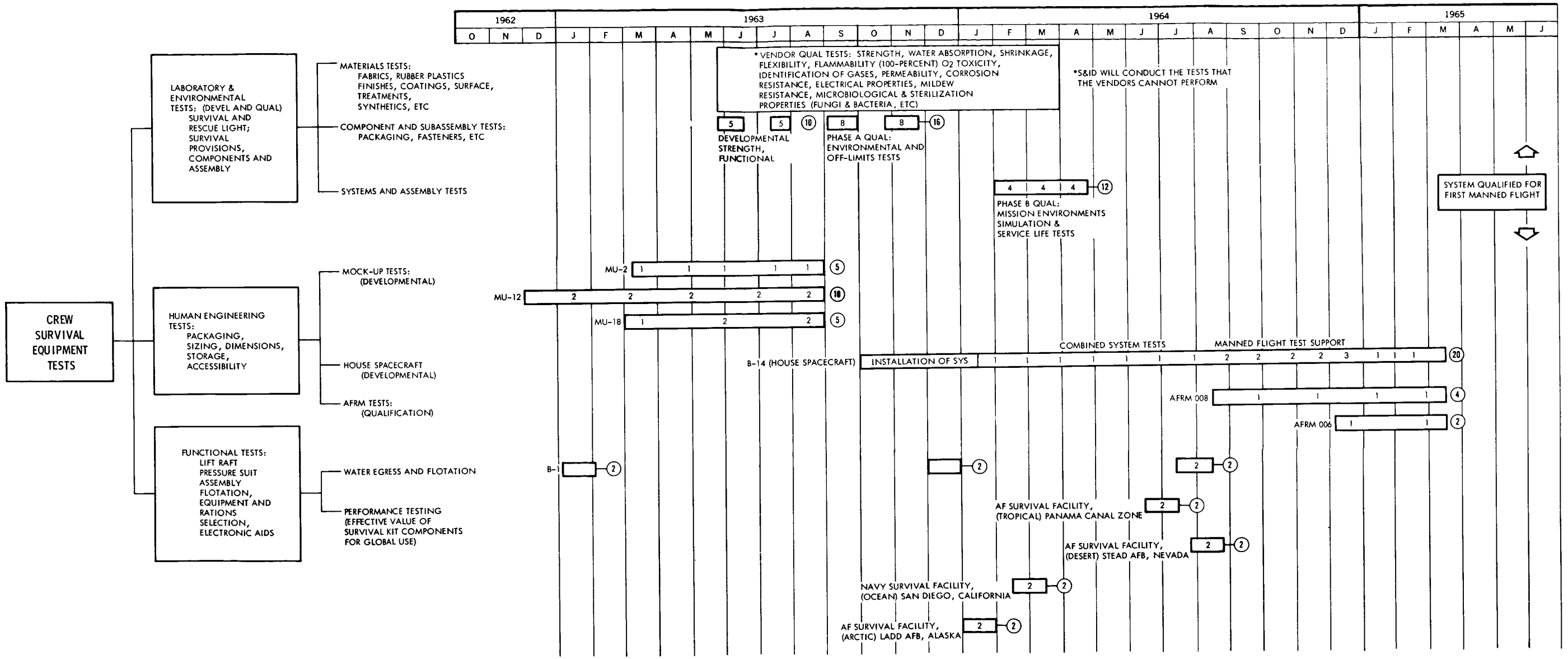

Figure 10-5. Systems Approach - Crew Survival Equipment Test Program

10.2.1.6 First-Aid and Biomedical Equipment Tests

10.2.1.6.1 Objectives. First-aid equipment and biomedical provisions must be verified against Apollo design criteria and the permissible environmental range for the command module. Interfaces between physiological instrumentation and spacecraft electronic systems must be achieved. First-aid supplies will be tested for performance-degrading pharmacological changes and possible additions to the cabin debris or aerosol containment loads in a joint S&ID-NASA effort. Items to be tested include the following:

Emergency medical kit
Dressing set
Oral drugs (pills) pack
Injectable drugs pack
Topical agents pack
Physiological clinical monitoring set
Personal radiation dosimeters (GFE)
Personal biomedical sensors instrument assembly (GFE)
Personal biomedical preamplifier instrument assembly (GFE)

10.2.1.6.2 Test Requirements.

10.2.1.6.2.1 Materials Tests. Individual components and packaging will be tested to evaluate such environmental influences as 100-percent oxygen and ionizing radiation on the stability of the first-aid kit components and medicinals. Containers and packaging will be tested in general accordance with MIL-E-5272C, except that levels of environments applied will be those commensurate with the anticipated maximum levels for the Apollo mission. (Refer to Volume III, Section 4.0.)

10.2.1.6.2.2 Human Engineering (Systems Compatibility). First-aid equipment, biomedical instrumentation, and NASA-furnished biosensors will be interfaced with the command module internal arrangement during house spacecraft. Evaluation of ECS interfaces will be integrated with the manned phase of the ECS breadboard tests. Additional evaluation will continue during simulation tests in simulator 1 with final ground qualification occurring during Airframe 006 and 008 tests.

10.2.1.6.2.3 Functional Performance Tests. Biomedical and first-aid items are NAA furnished and will be coordinated with the NASA prior to procurement.

[redacted]

10.2.1.6.2.4 Biomedical Integration. The following parameters will be included as pertinent to the bioinstrumentation evaluation:

1. Verification of compatibility with other spacecraft electronic systems and GSE during prelaunch. This includes signal clarity, clinical correlation, and absence of intersystem interference.

2. Ease of attachment, removal, and response under the range of Apollo environments. The portion of bioinstrumentation dealing with the transmission of physiological instrumentation data is a communications responsibility and will be monitored by life systems only as concerned with intelligibility at the ground monitoring receiver.

10.2.1.6.3 Equipment and Facilities. The biomedical integration program is reflected in Figure 10-6. Specific requirements include the following:

1. Laboratory testing will be conducted by S&ID Engineering Developmental Laboratories.

2. Developmental investigations will utilize evaluator 5, B-14, and the centrifuge program. They will be concurrent with human engineering evaluations and biomedical functional tests integrated with the ECS breadboard tests and will require both human subjects and appropriate pressure garment assemblies (the latter due to a necessary interface with the crew clothing subsystem).

3. Appropriate data bits will be recorded and retained for biomedical evaluation and correlation with standard clinical information and will result in the establishment of baseline information for use during manned flight.

10.2.1.6.4 Test Schedule. The test schedule for first-aid and biomedical equipment tests is shown in Figure 10-6.

10.2.2 Spacecraft (Crew) Systems Interface Tests

A comprehensive test program will evaluate the human engineering interfaces of the flight crew with systems and equipment installed in the command module. The crew systems human engineering test program presently includes the following:

Control-display systems
Crew systems tests
Illumination systems

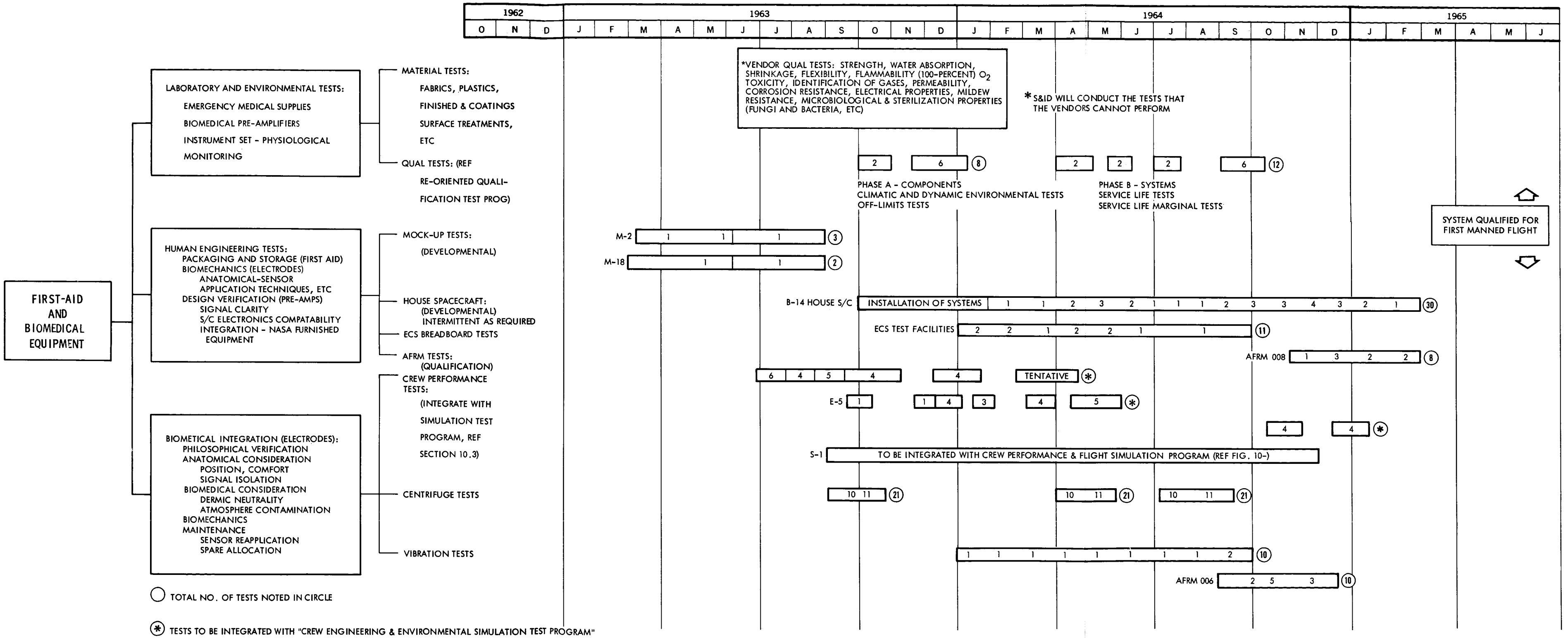

Figure 10-6. Systems Approach - First-Aid and Biomedical Equipment Test Program

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Food and water provisions
Waste management system
Environmental control system
GSE (checkout, auxiliary servicing, and handling)

Human engineering test requirements for the above equipment systems are defined in the following paragraphs.

10.2.2.1 Control-Display Systems Tests

10.2.2.1.1 Test Requirements.

10.2.2.1.1.1 Component Evaluation. The design and selection of individual control-display components will be verified for conformance with S&ID and NASA human engineering criteria and specifications.

10.2.2.1.1.2 Systems Evaluation. Evaluation of design and configurational layout of primary and secondary control-display systems for conformance with system functions criteria will be made. Functions analyses and task and time-line analyses of critical systems will be conducted to verify optimum layout of primary and secondary control-display systems.

10.2.2.1.1.3 Integrated Systems Evaluation. Design and configuration of integrated control-display systems will be verified for conformance with crew function and crew task allocation criteria. Crew task and crew functions analyses will be prepared, and link and time-line analyses will assure optimum configuration of integrated control-display systems.

10.2.2.1.1.4 Design for Maintainability (Ground and In-Flight). Maintainability design will be evaluated for conformance with ground and in-flight maintainability criteria. Human engineering analyses and simulated malfunction and alignment tests will determine the extent of maintenance, tools, and equipment requirements.

10.2.2.1.2 Equipment and Facilities. The control-display system test program will utilize test articles and facilities as shown in Figure 10-7. Specific requirements are as follows:

1. Design developmental tests will utilize equipment mock-ups and breadboards installed in engineering mock-ups 2, 12, and 18.

2. Systems evaluation and integrated systems evaluation will utilize developmental or first-run hardware installed in the house spacecraft B-14 or Airframe 006.

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3. Functional performance will be evaluated and qualified during the crew engineering and environmental simulation test program (see paragraph 10.3).

4. Human subjects fitted with operational pressure garment assemblies will be required.

10.2.2.1.3 Test Schedule. The control-display test program will be scheduled within the developmental framework shown in Figure 10-7.

10.2.2.2 Crew Systems Tests

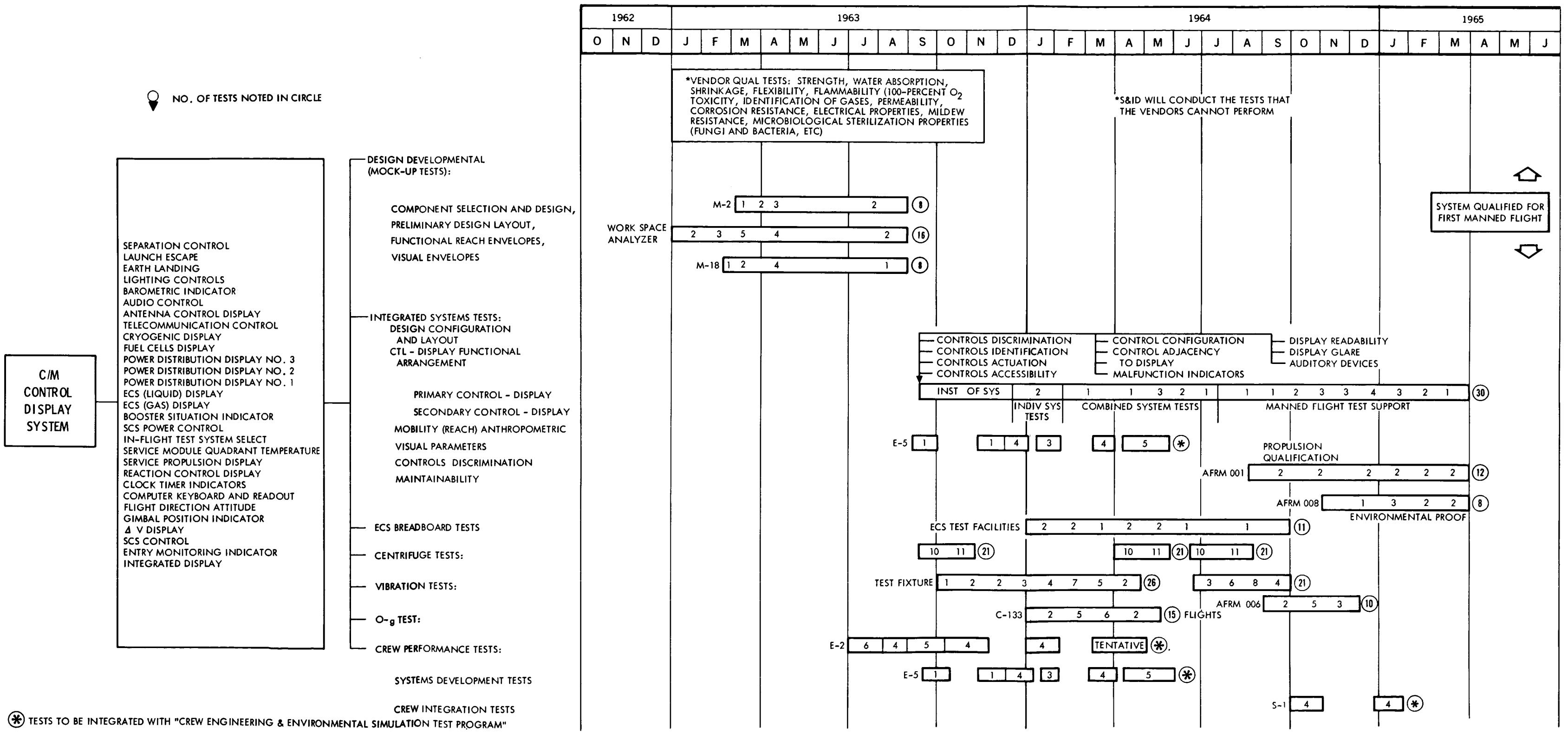
10.2.2.2.1 Test Requirements.

10.2.2.2.1.1 Command Module Interior Configuration. Verification of design and configuration of individual crew stations, primary and secondary duty stations, and rest and relief stations for conformance with Apollo crew systems design criteria will be sought. Fit-check evaluation tests with human subjects (10 through 90 percentile) and other tests will verify interior design conformance with human anatomical limitations. Seating, functional reach, visual envelopes, and crew mobility will be evaluated.

1. Crew Station Functional Arrangement. Design and configuration of crew station arrangements will be verified for over-all conformance with crew task and operations criteria. Crew task evaluations and simulated operational missions will be conducted to evaluate equipment accessibility and general cabin arrangements.

2. Storage Facilities and Attachment Fixtures. Design of storage facilities and attachment fixtures will be verified for compatibility with all nonstructural crew equipment (e.g., space suit storage, scientific equipment storage, tool kits, spares, etc.). Dimensions and configurations and size and shape of storage and attachment fixtures for the various equipment items in the cabin interior will be evaluated.

3. Maintainability Design (ground and in-flight). Over-all design and configuration of in-flight test provisions will be evaluated for conformance with S&ID and NASA in-flight maintainability criteria. Simulated malfunction tests will be conducted to determine the extent of maintenance requirements, tools, and equipment required.



⊛ TESTS TO BE INTEGRATED WITH "CREW ENGINEERING & ENVIRONMENTAL SIMULATION TEST PROGRAM"

Figure 10-7. Systems Approach - Command Module Control-Display Systems Human Engineering Test Program

10.2.2.2.1.2 Command Module Interior Color Evaluation.

1. Materials Tests. Laboratory and functional test requirements will be coordinated to ensure that the outgassing and trace gas contaminant properties of the paints and enamels selected for the Apollo system will not have harmful effects on the crew. Additional laboratory tests will evaluate reflectance, grease and stain resistance, reaction to oxygen, toxicity, and heat reflectance or absorption.

2. Cabin Interior Components. Performance tests will be conducted to evaluate visual comfort and controls discrimination. These tests are described in paragraph 10.3, Crew Engineering and Environmental Simulation Tests.

10.2.2.2.1.3 Windows and Shutters.

1. Design Evaluation. Window design will be evaluated for conformance with S&ID and NASA human engineering design criteria. Tests will be conducted to evaluate the field of view provided by the windows and shutters as related to the various couch adjustments and positions. Test requirements to verify crew protection from heat and a high-intensity illumination transients will be coordinated, as required.

2. Optical Design Evaluation. Laboratory evaluation tests will be conducted, as required, to assess the optical qualities of the windows and verify the provisions and interactions for use with cameras, periscope, telescopes, and sextant optical devices.

10.2.2.2.1.4 Docking Egress Provisions.

1. Human Engineering Design Verification. The docking transit tunnel and hatch design and configuration will be evaluated for conformance with S&ID and NASA crew system design criteria. The dimensions of the transit tunnel will be verified for anthropometric compatibility. The operation of the system will be functionally verified, and tests will be conducted to evaluate ground and in-flight maintainability provisions.

2. Ingress and Egress Tests. Tests will functionally evaluate the design provisions for crew ingress-egress during all Apollo mission phases (ground and in-space, nominal and emergency, and under zero-g conditions). These tests will be conducted with human subjects (10 through 90 percentiles) equipped with pressurized suits and the portable life support system. Tests

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will be performed under zero-g conditions and in altitude chambers to provide realistic environmental conditions. Underwater tests will be performed to evaluate emergency egress during submerged conditions.

10.2.2.2.1.5 Access Hatches.

1. Human Engineering Design Verification Tests. The crew access hatch will be evaluated for design and configuration conformance with S&ID and NASA crew system design criteria. Tests will be conducted to evaluate the hatch dimensions, configuration and location for compatibility with crew anthropometrics, and location and operational requirements to ensure optimum crew utilization. Operation of the system will be functionally evaluated, and the provisions for ground and in-flight maintenance will be tested.

2. Ingress and Egress Tests. Tests will be conducted with human subjects (10 through 90 percentile) to evaluate the hatch and related systems for optimum crew ingress-egress provisions. These tests will be implemented with mock-up tests and will include simulated land, water, nominal, and emergency egress conditions. Underwater tests will evaluate emergency egress, if submerged.

10.2.2.2.2 Equipment and Facilities. Cabin arrangement tests will utilize test articles and facilities as shown in Figure 10-8. Specific requirements are as follows:

1. Design developmental tests will utilize equipment mock-ups and breadboard articles installed in the engineering mock-ups 2, 12, and 18.

2. Human engineering tests will utilize developmental or first-run hardware installed in the house spacecraft B-14 or Airframe 006.

3. Functional performance tests will be conducted during the crew engineering and environmental simulation test program (see paragraph 10.3).

4. Dynamic qualification tests will be performed as part of the environmental proof-test program (see Volume V, Multiple Systems Tests). Zero-g tests will require utilization of the USAF C-135 zero-g laboratory.

5. Human test subjects fitted with operational pressure suits will be required.

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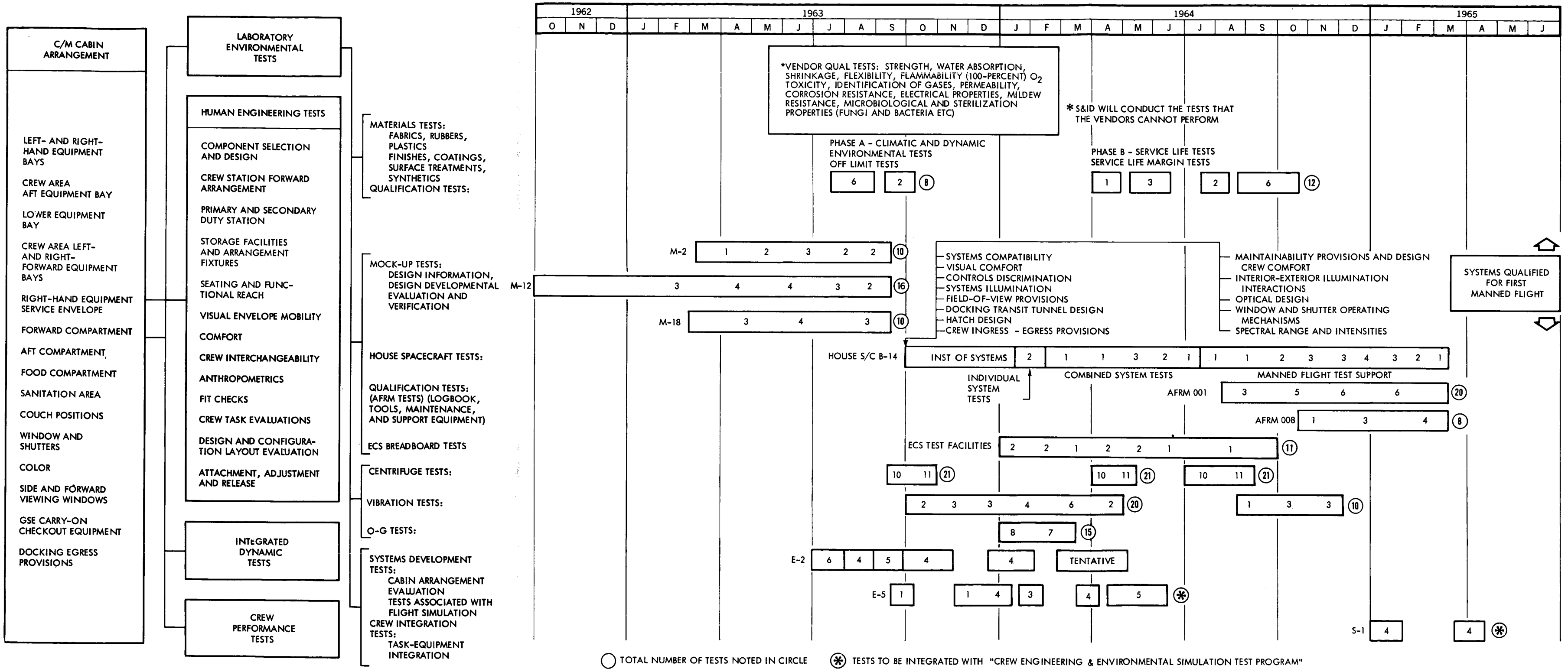

Figure 10-8. Systems Approach - Command Module Cabin Arrangement Test Program

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10.2.2.2.3 Test Schedule. The cabin arrangement test program will be scheduled within the developmental framework shown in Figure 10-8.

10.2.2.3 Illumination Systems Evaluation

10.2.2.3.1 Test Requirements.

10.2.2.3.1.1 Subjective Evaluation. Testing will be accomplished to assure an adequate visual environment as outlined in specifications and requirements established by S&ID Life Systems and NASA for crew operations (MC 999-0005 and 0007). Operations and instructions will be verified using various means of illumination, light control devices, and display presentations in conjunction with a simulated background of appropriate space-ambient luminary sources. Controlled subject performance tests will also evaluate optical illusions, parallax, visual comfort and fatigue, reflections, and tolerance to predicted visual intensities.

10.2.2.3.1.2 Objective Evaluation.

1. Tests will be conducted to assess illumination systems operation and interaction, color, contrasts, display presentation clarity, lighting control location and actuation, fixture design and placement, brightness levels, filter operation, emergency provisions, color of light, intensity levels, reflection, glare, and lamp distribution as pertinent to the over-all spacecraft environment.

2. EDL illumination equipment and control devices testing will be monitored in order to confirm the following:

   a. Photometric brightness of illumination produced by equipment

   b. Color of equipment and illumination by comparison or by spectrophotometric methods

   c. Contrast ratios

   d. Equipment compatibility with environmental conditions as related to man-machine interaction

   e. Glass requirements

   f. Grease and stain resistance of finishes

[redacted]

[redacted]

g. Actions of various coatings, such as light reflective and absorbing coatings

h. Interior and exterior lighting interaction photometrically and spectrophotometrically

3. Specific systems, equipment, and materials which will undergo appraisal of the following:

a. Interior floodlighting, consisting of arrangement of fixtures, system operation, colors, gloss, contrasts, and color of lighting

b. Interior integral lighting, consisting of application, system operation, color of finishes and gloss, contrasts, color of lighting, and MIT equipment

c. Effectivity and use of portable light

d. Exterior illumination, consisting of flashing, position, and docking flood lights

e. Emergency handle lighting (buttons)

f. Rescue lighting aids

10.2.2.3.2 Equipment and Facilities. Subcontractor and vendor facilities will be used to the fullest possible extent in achieving over-all test objectives. However, where subcontractor or vendor facilities are inadequate, S&ID facilities will be used to complete qualification requirements. Representative contractor facilities which are certain to contribute to the Apollo illumination systems evaluation include the following:

1. Engineering Development Laboratories (EDL)

2. Evaluator 5 and mock-up 12

3. Lighting and vision development dome

4. Boilerplate 14

5. Airframe 008

6. Miscellaneous meters, projectors, lighting equipment, photometers, and spectrophotometers

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10.2.2.3.3 Test Schedule. The sequence of testing will be scheduled within the framework illustrated in Figure 10-9.

10.2.2.4 Food and Water Provisions

10.2.2.4.1 Test Requirements.

10.2.2.4.1.1 Water System Evaluation.

1. Tests of the water system will be conducted to verify conformance with S&ID and the NASA human engineering design criteria.

2. Water quantity, potability, and temperature control will be evaluated in conjunction with necessary food preparation activities during the crew engineering and environmental simulation test program. (Refer to paragraph 10.3.)

3. A primary system effort will be expended in continuous evaluation of the water quantity versus metabolic and ECS requirements. Survival requirements will be verified to reflect fuel cell water, in addition to container supplies, and to be sufficient for any postlanding situation.

10.2.2.4.1.2 Drinking Container Design. Human engineering tests will be conducted for the purpose of confirming container dimensions, stowage, and biomechanical properties. Performance under weightlessness will be included as a basic-phased effort of man-machine interface.

10.2.2.4.1.3 Food System Evaluation. Testing will be performed to verify items, palatability, storage, and preparation in terms of Apollo design criteria. Valid data on such parameters will be gained through habitability studies extending over several days. (Refer to paragraph 10.3.)

10.2.2.4.1.4 Food Container Design. Dimension, storage, and biomechanics will be developed through extensive evaluator, simulator, and weightlessness trials in cooperation with the subcontractor. Compatibility with the food preparation system will be assured, and time-line analysis will be conducted to establish relationships with routine and emergency crew function.

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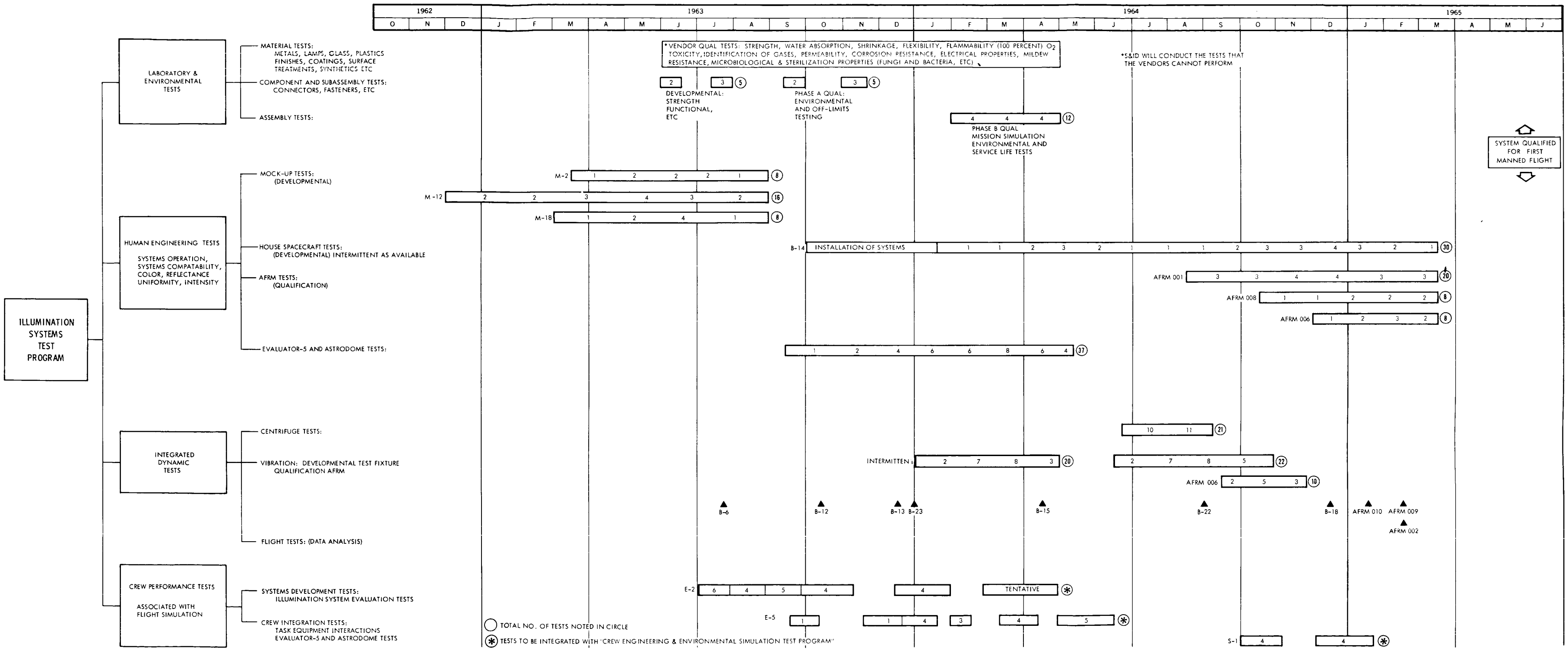

Figure 10-9. Systems Approach - Illumination Systems Test Program

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10.2.2.4.2 Equipment and Facilities. The food and water provisions test program will use the facilities shown in Figure 10-10. Specific requirements include the following:

1. Human engineering developmental testing will be conducted in mock-ups 2 and 18. Prototype spacecraft articles will be interfaced in house spacecraft 1 (B-14).

2. Prototype hardware will utilize the preceding vehicles, as available, and will be terminally evaluated in simulator 1 during the crew engineering and environmental simulation test program prior to testing of qualification items.

3. Ground qualification tests will be integrated with the ECS breadboard test program.

4. Human subjects will be utilized exclusively in keeping with the intimate metabolic relationship while maintaining a continuous interface with the space suit assembly (SSA) and the accompanying adverse environments that require the use of the personal equipment level of pressure protection.

10.2.2.4.3 Test Schedule. Food and water systems test schedules are as shown in Figure 10-10. The definition of individual test dates, as equipment availability is chronologically defined, is also shown in the test schedule.

10.2.2.5 Waste Management System

10.2.2.5.1 Test Requirements.

10.2.2.5.1.1. Collection Device Evaluation. The design of feces, urine, and oral waste collection devices and receptacles will be evaluated for compatibility with human anatomy and lower equipment bay restraint.

10.2.2.5.1.2 Collection System Evaluation. The functional design of the feces and urine collection systems will be evaluated for conformance with Apollo crew systems design criteria. Functional tests of the collection system for human waste using human subjects during simulated Apollo missions will be conducted.

10.2.2.5.1.3 Bacteriological Control. Laboratory tests will be conducted to evaluate the bacteriological control capabilities of the management system for human waste.

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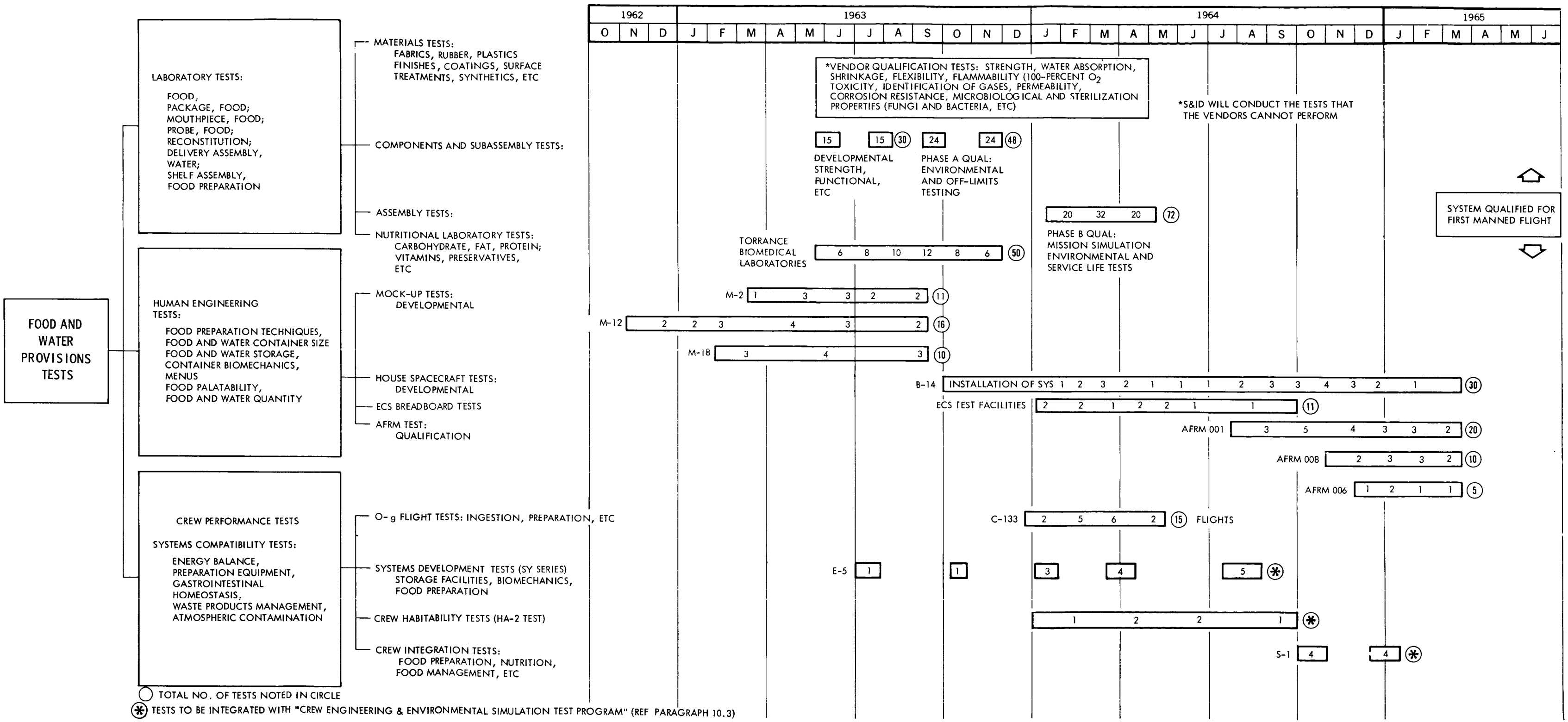

Figure 10-10. Systems Approach - Food and Water Provisions Test Program

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10.2.2.5.2 Equipment and Facilities. The waste management system test program will utilize test articles and facilities shown in Figure 10-11. Specific requirements are:

1. Design developmental tests will utilize equipment mock-ups and breadboards installed in the engineering mock-ups 2, 12, and 18.

2. Human engineering design evaluation tests will utilize developmental or first-run hardware installed in the house spacecraft B-14.

3. Performance and preliminary bacteriological control tests will be conducted during the crew engineering and environmental simulation test program. (See paragraph 10.3.)

4. Waste system functional bacteriological control tests will be integrated with the ECS breadboard manned test program.

5. Qualification tests will utilize final design articles installed in the house spacecraft Airframe 006 and in the environmental proof spacecraft Airframe 008.

6. Human test subjects will be required.

7. Bacteriological control laboratory tests will be conducted by the S&ID Applied Sciences Laboratory.

10.2.2.5.3 Test Schedule. The waste management test program will be scheduled within the developmental framework shown in Figure 10-11.

10.2.2.6 Environmental Control System Tests

10.2.2.6.1 Test Requirements.

10.2.2.6.1.1 Subcontractor Tests. Design development verification tests for the environmental control system design and function will be conducted by the subcontractor as outlined in Section 5.0, Environmental Control System. Systems will be cognizant of all system level tests and monitor those which may reflect Apollo life systems integration requirements.

10.2.2.6.1.2 Human Engineering Tests. Testing is necessary to verify design criteria and examine man-machine interfaces pertinent to atmospheric and thermal control. Validation of human input criteria to the system, including biomechanical areas, such as the CO_2 and odor canister replacement, will be accomplished on a concurrent basis with ECS control and panel evaluation. This information will be integrated with

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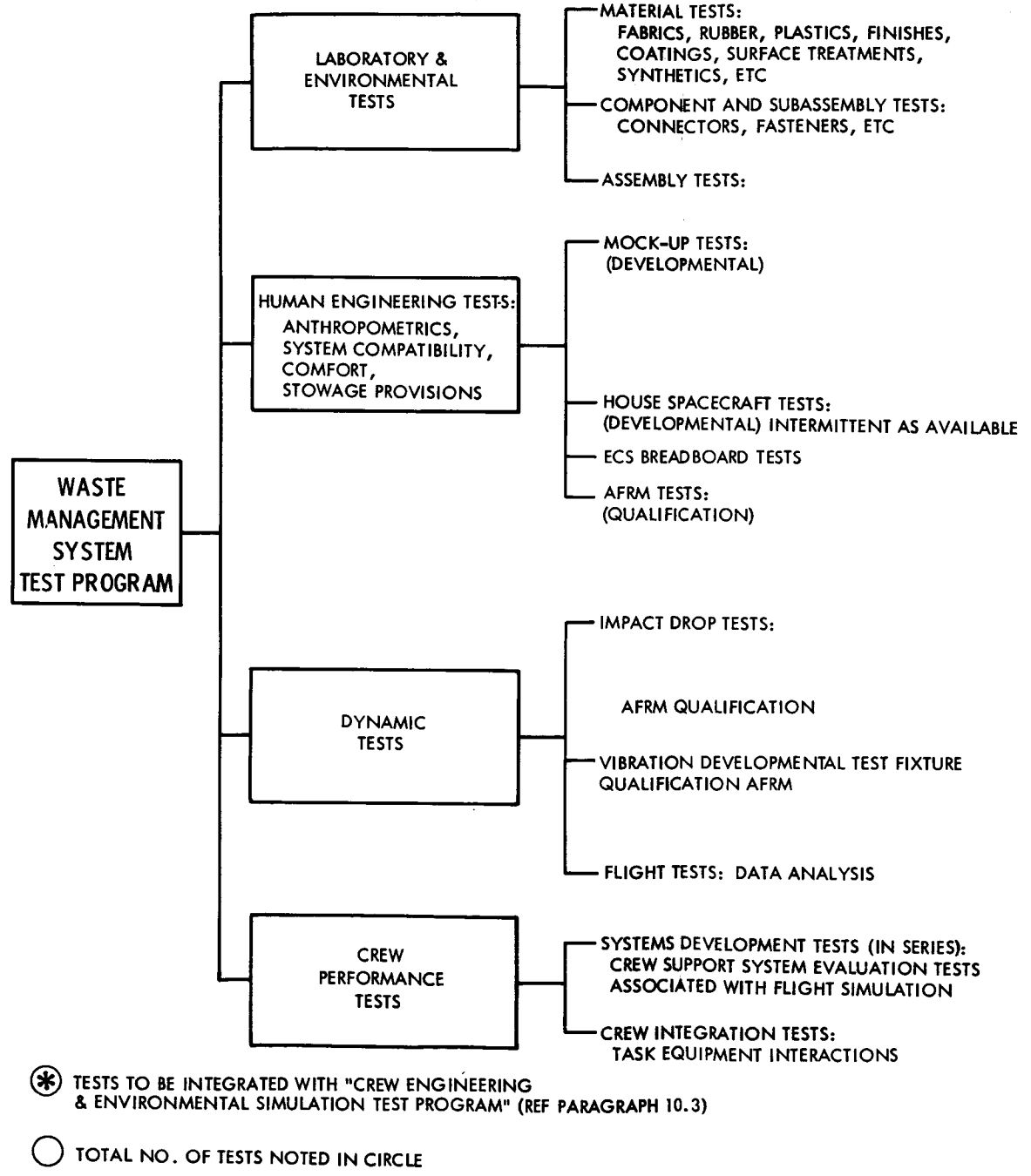

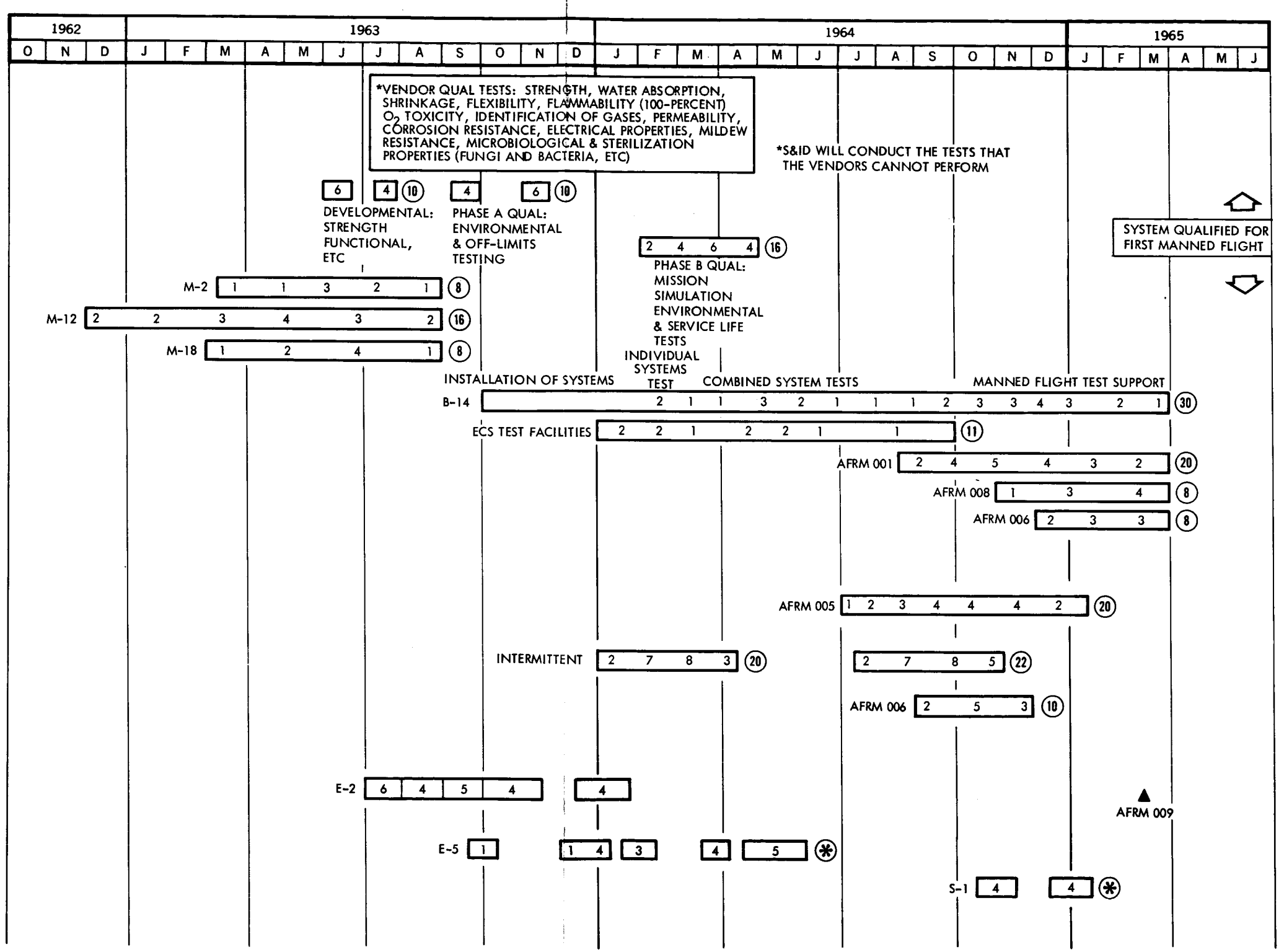

Figure 10-11. Systems Approach - Waste Management System Test Program

the physiological constraints defined during systems verification of the subcontracted system.

An associated effort will be the integration of environmental control components with personal hygiene, waste management, and nutritional subsystems. Tests described herein will be a part of the ECS breadboard tests.

10.2.2.6.1.3 Life Systems Verification Tests. S&ID is responsible for integration of subcontractor equipment into the over-all Apollo vehicle system. A life systems functional verification of mission compatibility will accompany such an integration and will assure compatibility with other personal support subsystems. Life systems will furnish requirements for evaluations of crew ECS interfaces during the manned phase of the breadboard tests. Evaluations by Life Systems during these tests will include the following:

1. Acceptibility of the shirtsleeve environment in the command module
2. Space suit assembly operation in the command module
3. Gas partial pressures, total pressure, and contaminant control
4. Metabolic balance for the Apollo mission
5. Charging provisions for the personal life support system
6. Consumption rates of atmospheric make-up gases under normal leak rate and emergency pressure loss
7. Command module air-flow distribution
8. Removal of command module particulate debris by vacuum cleaning
9. Reliability and function of pressure relief, flow limiting, and postlanding safety devices
10. In-flight maintenance and expendable absorbent replenishment
11. Flood flow postdecompression
12. Repressurization from vaccum

[redacted]

10.2.2.6.2 Equipment and Facilities. S&ID conducted verification tests will utilize the test articles and facilities as shown in Figure 10-12.

10.2.2.6.2.1 Human Engineering Facilities. Mock-up 18 and B-14 (house spacecraft 1) will be used to check the man-machine interface, and the system will be verified in Airframe 006 (house spacecraft 2). This program will provide the necessary feedback to the subcontractors and will assure successful mating of all life support systems at the flight test level.

10.2.2.6.2.2 Evaluation Facilities.

1. Verification of prototype display and control concepts will be conducted in evaluator 5 in conjunction with other personal support subsystem tests. These tests will utilize simulated ECS components and displays and will stress man-machine functions, as related to necessary physical tasks and systems surveillance.
2. Full ECS operation, under 5-psi, 100-percent oxygen, will be accomplished in the Downey man-rated space chamber utilizing the ECS test capsule in conjunction with the ECS breadboard test program. Biophysical and biochemical functions will be assessed as a part of the habitability studies and crew engineering and environmental simulation test program. (Refer to paragraph 10.3.)
3. Qualification tests using man-rated production components will be conducted with both the ECS breadboard high-vacuum chamber and Airframe 003; they will confirm the final aspects of reliability and the achievement of an acceptable man-machine relationship.
4. Metabolic simulators will precede human subjects equipped with full pressure suits and will provide baseline information for follow-on toxicity and bacteriological investigations.

10.2.2.6.3 Test Schedule. The general time-test relationships are shown in Figure 10-12. Specific tests that fall within this framework include the following:

1. 4-hour system checkouts
2. 8-hour system checkouts
3. 3-day system checkouts
4. 14-day habitability—environmental tests, two programmed. (Refer to paragraph 10.3.)

10.2.2.7 GSE (Checkout, Auxiliary Servicing, and Handling Equipment) Tests

10.2.2.7.1 Test Requirements.

10.2.2.7.1.1 Component Evaluation. The design of GSE display components will be verified for conformance with NASA and/or S&ID human engineering specifications and recommendations.

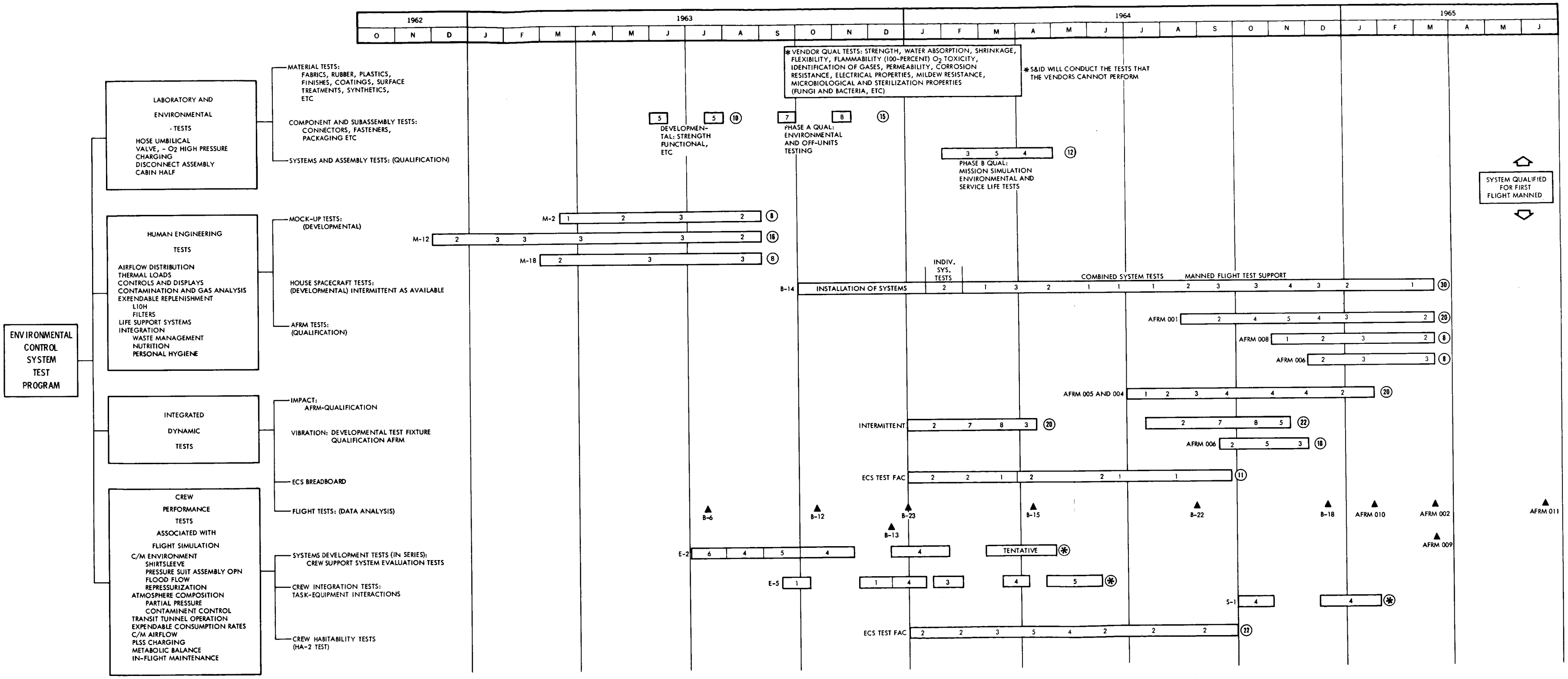

Figure 10-12. Systems Approach - Environmental Control System Test Program

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10.2.2.7.1.2 System Evaluation. Design of GSE control-display panel interfaces will be evaluated to ensure optimum functional grouping. Performance tests (functions, task and time-line, etc.) will be conducted to verify optimum configurational layout of GSE control-display panel and console interfaces.

10.2.2.7.1.3 Integrated Systems. Integrated performance tests will be conducted to verify GSE-flight vehicle interface compatibility (equipment accessibility, ease of connections, communications, safety, etc.) to assure optimum configuration of the integrated systems.

10.2.2.7.1.4 Handling and Servicing Equipment. Tests will be conducted to evaluate human engineering compatibility of Apollo checkout and handling and servicing systems and procedures with the over-all launch complex. The design of handling equipment will be verified for conformance with performance criteria (S&ID and NASA criteria specifications) for handling and storage of all systems.

10.2.2.7.1.5 Procedures. Performance tests will be conducted to evaluate systems and combined systems checkout procedures. Functions, task, and time-line data will be collected to verify combined systems checkout, procedures design, communications, and safety.

10.2.2.7.1.6 Systems Maintainability. GSE checkout, auxiliary servicing and handling systems will be evaluated for conformance with human engineering maintainability criteria (S&ID and NASA specifications). Malfunction and alignment simulation tests will verify the over-all design, configuration and procedures for conformance with GSE systems maintainability criteria.

10.2.2.7.2 Equipment and Facilities. Specific requirements for the GSE (checkout, auxiliary servicing, and handling equipment) systems are as follows:

1. Initial design developmental human engineering tests will be conducted with breadboard mock-ups of GSE control panel and console interfaces as required to solve specific problem areas.

2. Integrated systems tests and maintainability and procedures evaluations will be accomplished in conjunction with the house spacecraft test program, B-14 and Airframe 006.

3. Functional and operational man-machine compatibility tests will be conducted during the flight test program. (Refer to Volume V.)

10.2.2.7.3 Test Schedule. The GSE test program will be scheduled within the developmental framework shown in Figure 10-13.

[redacted]

TEST ITEM —		HUMAN ENGINEERING FUNCTION DURING TEST	APOLLO VEHICLE BEING TESTED BY GSE
● I. PRE-TESTS FOR ACCEPTANCE:			
A. CONTROL DISPLAY PART	1. PANEL: BUTTON, KNOB, LIGHT, METER, SWITCH, ETC a. COMPLIANCE WITH MIL-STD-803 REQUIREMENTS	VISUAL INSPECTION	MOCK-UP NO. 9 AND 11
B. PANEL LAYOUT GEOMETRY AND PARTS FUNCTIONS EVALUATION.	1. PANEL CONFIGURATION: a. COLOR GROUPING, LIGHTING, SPACING, MARKING, ETC 2. FUNCTION COMPATIBILITY: a. INTERPRETATION LIMITATION EXCEEDED	VISUAL INSPECTION	
C. COMPONENT PANEL ASSEMBLY (LAYOUT)	1. EVALUATION OF PARTS OF = A & B	DRAWING REVIEW	
D. MAN EQUIPMENT FUNCTION COMPATIBILITY	1. OPERATIONS PERFORMANCE: TEST PERSONNEL SAFETY EQUIPMENT/APPAREL a. SAFETY FACTORS b. CAPABILITY EXCEEDED c. FUNCTION/BEHAVIOR PECULIARITY	TEST AND OBSERVATION	
● II. SYSTEMS PERFORMANCE TESTS:			BOILERPLATE NO.: 6 (C/M PAD ABORT) 9 (VEHICLE FOR DYNAMIC TESTS) 12 (C/M MAX Q - LES VERIFICATION) 13 (1ST S/C FOR LAUNCH ENVIRONMENT) 14 (HOUSE SPACECRAFT NO. 1) 15 (2ND VEHICLE FOR LAUNCH ENVIRONMENT) 16 (VEHICLE FOR MICROMETEROID EXPERIMENT) 18 (STRUCTURAL QUAL & EDS C/O) 22 (HIGH-ALTITUDE ABORT) 23 (BACKUP FOR BP-6, BP-12) AIRFRAME NO.: 001 (PROPULSION SYSTEM QUAL C/M NONFLYABLE) 002 (C/M FOR MAX g ABORT AND C/M STRUCTURAL DEMONSTRATION) 006 (HOUSE SPACECRAFT NUMBER 2) 009 (UNMANNED QUALIFICATION FLIGHT) 010 (C/M FOR PAD ABORT) 011 (S/C FOR 1ST MANNED FLIGHT)
A. PROFICIENCY STUDY	1. MAN/MACHINE TASK a. EFFICIENCY - MINIMIZED REDUNDANCY, WORK LOAD LIMITATION, MALFUNCTION CORRECTION EFFECTIVENESS, CREW COORDINATION 2. DATA HANDLING AND COMMUNICATIONS EFFECTIVENESS	VERIFY CRITERIA AND MONITOR TEST	
B. FUNCTIONAL GROUPING.	1. INTERFACE: CABLING, CONNECTOR MATING a. ANTHROPOMETRY, WORK SPACE CONFIGURATION 2. MARKING: a. COMPLIANCE WITH HUMAN ENGINEERING REQUIREMENTS, USE OF PLACARDS	ESTABLISH REQUIREMENT AND MONITOR APPLICATION	
C. PERFORMANCE-MAN EQUIPMENT OPERATIONAL COMPATIBILITY	1. OPERATOR: COMPREHENSIVENESS, FATIGUE, SKILL LEVEL, TEAM COORDINATION, CAPABILITY EXCEEDED, ALERTNESS 2. EQUIPMENT: CONTROL/DISPLAY ACTION EXCEEDS HUMAN COMPREHENSION. 3. MAN/EQUIPMENT: HANDICAP, IMPROPER TOOL OR USE, FUNCTION CONTINUITY	OBSERVE FOR REQUIREMENT VERIFICATION	
D. ENVIRONMENTAL DISTRACTION	1. CLIMATIC 2. MAN-MADE: a. ILLUMINATION, NOISE, TEMPERATURE, HUMIDITY, RADIATION, ETC b. TOXIC GAS, ODOR, BLINKING LIGHT, AND INTERRUPTION, COMPLIMENT RESTRICTION	MONITOR AREA	
E. COMPLIANCE WITH TEST CRITERIA	1. CHECKLIST ITEMS: ITEMS TO BE CONSIDERED DURING TESTS 2. DOCUMENTATION: LSTR'S, REPORTS 3. DATA HANDLING: DATA ACQUISITION, CODING, PROCESSING, AND ACKNOWLEDGEMENT	SURVEILLANCE FOR OPERATOR HUMAN FACTORS APPLICATION	
● III. SYSTEMS MAINTAINABILITY: A. CALIBRATION, TROUBLESHOOTING, & PARTS REPLACEMENT ACCESSIBILITY (ANALYSIS)	1. ANTHROPOMETRY: WORK SPACE ALLOCATION 2. PROPER TOOL: SERVICING, HANDLING, CALIBRATION, AND REPAIR OPERATIONS 3. EFFICIENCY ITEM: TOOL HOLDER (AVAILABILITY); BRACKET FOR TEST EQUIPMENT 4. INTERCHANGEABILITY: SPARE, STANDARD PART, MARKING	ANALYSIS VERIFICATION	
B. MAINTENANCE PERFORMANCE	1. COMPREHENSIVENESS: TIME/MOTION STUDY 2. ALERTNESS 3. MOTIVATION	VALIDATION CHECK	
C. COMPLIANCE WITH GOOD HOUSEKEEPING PRACTICE	1. CHECK HOUSEKEEPING EQUIPMENT: VACUUM CLEANER, RAG CONTAINER, ETC a. STOWAGE AREA: SPONTANEOUS COMBUSTION PREVENTION	MONITOR PROCEDURE	
● IV. COMMON CHECKS. A. DATA HANDLING	1. EFFECTIVENESS: a. USE OF DATA SYSTEM b. USE OF EQUIPMENT HISTORY CARDS c. CODING METHOD, DATA PROCESSING METHOD	MONITOR SYSTEM	
B. MALFUNCTION AND PROBLEM	1. CHECK USE OF NCR'S AND NCAR'S 2. CHECK COMMUNICATIONS EFFECTIVENESS	MONITOR SYSTEM	
C. COMPLIANCE WITH COMMUNICATIONS PROCEDURE	1. SURVEY "HOT SPOTS" IN COMMUNICATION BREAKS 2. MAKE COMPLETENESS SURVEY	SURVEY COMMUNICATIONS CHAIN	
D. PHYSIOLOGICAL DEMANDS EQUIPMENT	1. CHECK AREA FOR AVAILABILITY OF BIOPHYSICAL EQUIPMENT a. FACILITY: DRINKING WATER, REST ROOM, ETC, HYGIENE b. REST PERIOD, SANITARY EATING AREA	COMPARE CODE WITH FACILITY REGULATIONS	
E. SAFETY PRACTICE	1. EMERGENCY EVALUATION: a. EXIT MARKING, OVERVIEW OF TEST COMPLEX b. DECONTAMINATION MEASURE, SHOWER 2. AREA CLEARANCE: CABLING/PLUMBING, OILY/WET FLOOR	SAFETY MONITORING	
F. COMFORT	1. CONVENIENCE OUTLET: ELECTRICAL METER, SOLDERING IRON, ETC 2. PERSONNEL EQUIPMENT: FLASHLIGHT, SUN GLASSES, ETC	SURVEY AREA BETWEEN TESTS	

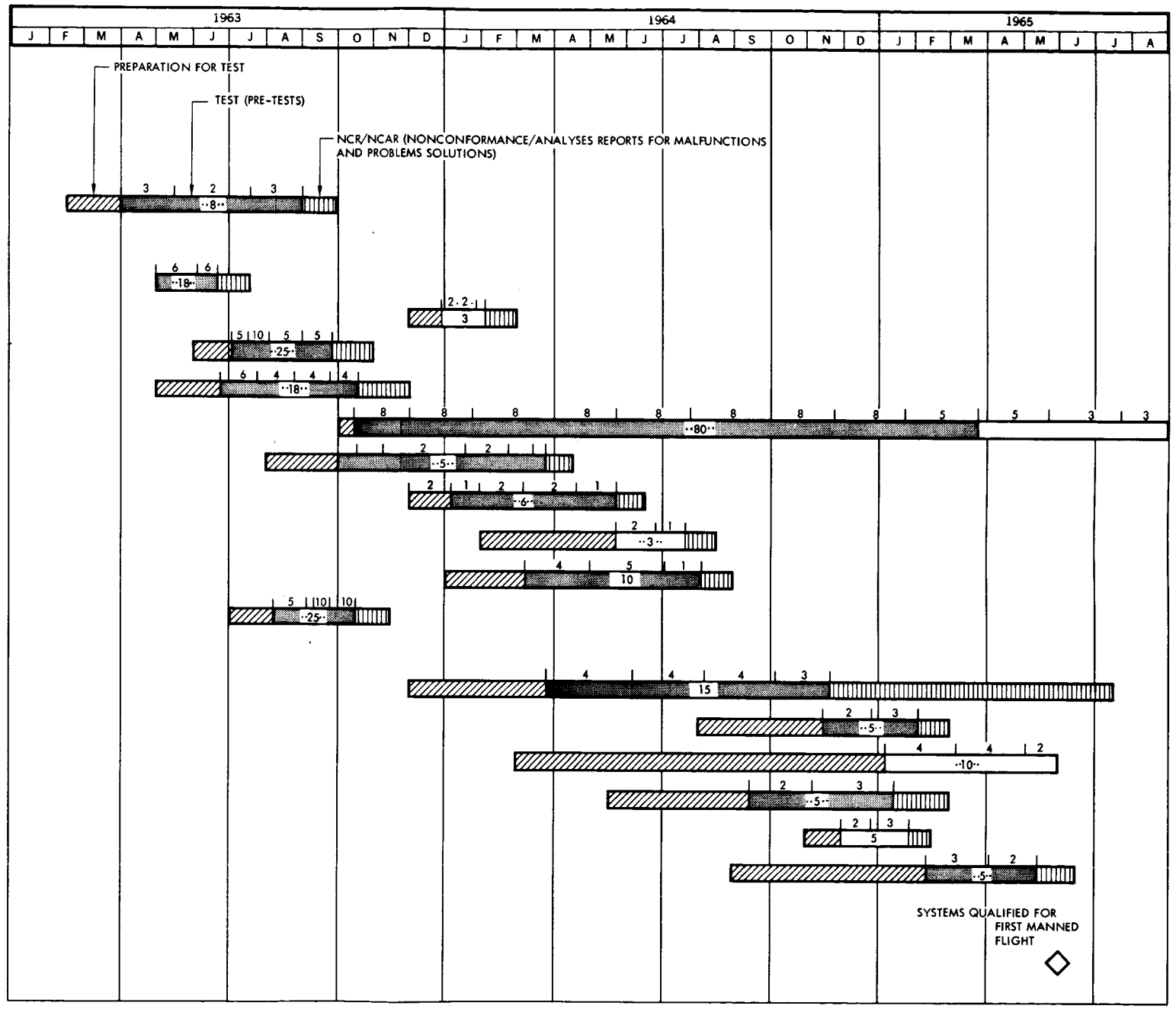

Figure 10-13. Human Engineering Function Schedule for Apollo GSE Tests

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10.3 CREW ENGINEERING AND ENVIRONMENTAL SIMULATION TEST PROGRAM

The simulation program is designed to accomodate many of Life Systems' requirements. These include verification of displays and controls, lighting, cabin arrangement, crew/systems interactions, crew performance, crew integration, space crew/ground crew interactions, C/M crewman LEM crewman interactions, in-flight maintenace and safety, task analysis, physiological acceptability of Apollo environment, food and waste management, work-rest cycle, crew effects of expected acceleration, vibration and noise levels, and such special problems as exterior vision, sun shafting, etc.

The simulation test program is arranged in a number of mission phases and test series that support the flight performance and control (FPC) program. The static base, systems development tests previously appearing in this document are now incorporated in the current mission phase simulations. These follow a logical pattern beginning with simple systems and simple one-man tasks and culminating in tests with full crews and total systems operating in environments as nearly approximating Apollo conditions as is possible with available facilities. Qualification tests in airframe vehicles follow the evaluation and verification tests in simulators and house spacecraft.

The earliest simulations begin with a single component (e. g., FDAI and hand controller) and gradually add components until the full system complex at one duty station is simulated. As the tests progress, refinements are made in configuration of displays and controls, location, lighting, crewman tasks and crew performance. The tests conclude with tests of prototype systems.

Critical systems for boost-abort and entry will be further verified during the dynamic base simulation (Dy) series in manned centrifuge and shake table tests. These tests will also contribute valuable physiological data with respect to crew performance capabilities.

Refinement in crew interaction, task loading and task analysis verification are accomplished in the crew integration (In) series. Here two and/or three subjects, for appropriate phases, will function during simulated critical mission phases. In the first of the two In studies, only critical phases will be examined. These will include such phases as navigational sighting and mid-course correction, high gain antenna positioning, manual control of the RCS and PUCS fuel management, and preparation for entry and recovery. During the second In study, contingencies and in-flight maintenance will be added to the critical mission phases, and pressure suit donning and operation will be emphasized.

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The habitability (Ha) series will evaluate biomedical factors, food and waste management, task analysis, work-rest cycles, crew performances, and cabin arrangement. The first Ha study will be a 3-man, 14-day simulation. Flight dynamics data will be minimal, but work loads will closely approximate those of Apollo. The third (and fourth, if requested by NASA) will be conducted in the ECS test capsule with breadboard ECS. It will contain a 5-psia, 100-percent oxygen environment, and in the course of the test(s) emergency pressure suit operations at 3.5 psia will be performed. The second Ha study will be a 1-man, 3-day emergency earth return simulation. Stress will be placed on evaluation of systems arrangement to permit a successful 1-man return. In this case the trajectory and entry data will be critical measures of performance.

Due to the criticality of LEM operations and navigational sighting, two separate simulation series are scheduled. This scheduling has permitted study of these phases at an early date. One series, designated TDR (transposition, docking, rendezvous and LEM interface), examines in detail all aspects of the interrelationships between the C/M and the LEM from the crew point of view. Particular emphasis will be placed on sensors, systems, and sighting aids which will ensure the total success of the lunar mission. The navigational (Na) series utilizes a very simple simulation at the outset and is scheduled to develop into a fully functional G&N simulation operating in conjunction with all associated components and systems.

In summary, the simulation program consists of seven series of tests, as follows:

1. Mission phases
2. Dynamic base
3. Qualification testing
4. Crew integration
5. Habitability - environment
6. Transposition, docking, and rendezvous (including LEM interface)
7. Navigational studies.

10.3.1 Mission Phases

10.3.1.1 Boost and Abort Phase

[redacted]IDENTIAL

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10.3.1.1.1 Boost and LES Abort. (Simulation of the critical mission launch, boost and LES abort phases.)

10.3.1.1.1.1 Objectives.

1. Evaluate problems which arise during the abort portion of the Phase I centrifuge program.

2. Validate operational techniques involving manual operations of the S/C systems during LES abort.

3. Validate task loading during launch, boost, and LES abort.

4. Evaluate the ability of the pilot to initiate RCS fuel and oxidizer dump and ELS procedures during the postabort period.

10.3.1.1.1.2 Test Requirements.

10.3.1.1.1.2.1 Task.

1. Monitor displays during the critical phases of launch and boost.

2. Initiate LES abort sequence upon detecting a critical S/C systems failure.

3. Initiate emergency manual backup abort system dependent upon failure in manual abort system.

4. Perform postabort operation.

10.3.1.1.1.2.2 Variables.

1. Manual versus manual-backup LES abort system

2. Pressure garment, pressurized versus nonpressurized

3. Controls and displays

10.3.1.1.1.2.3 Measurements.

1. Time required to detect possible abort situation

2. Time required to initiate abort sequence

3. Accuracy of manual abort and post-abort procedure

[redacted]

4. Accuracy of task analysis with respect to correct abort procedures.

10.3.1.1.1.2.4 Design.

1. Schedule: To be determined.

2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.1.3 Equipment Requirements.

1. Latest Apollo controls and displays

2. Pressure garment assembly

3. Crew couches

4. Communication

5. Video coverage

6. Vehicle: Evaluator to be determined.

7. Computers: To be determined.

10.3.1.1.1.4 Facilities. S&ID facilities will be used.

10.3.1.1.1.5 Test Schedule. The test schedule for the boost and LES abort phases is shown in Figure 10-14.

10.3.1.1.2 S/M Abort I. (Simulation of important spacecraft systems in a single plane trajectory)

10.3.1.1.2.1 Objectives.

1. Develop operational techniques involving manual operations of the S/C systems during S/M abort.

2. Evaluate G&N, SCS, C&D, and manual capability for performing the basic S/M abort maneuvers.

3. Evaluate automatic and manual failure detection and switching.

4. Evaluate the adequacy of available back-up and/or redundant systems.

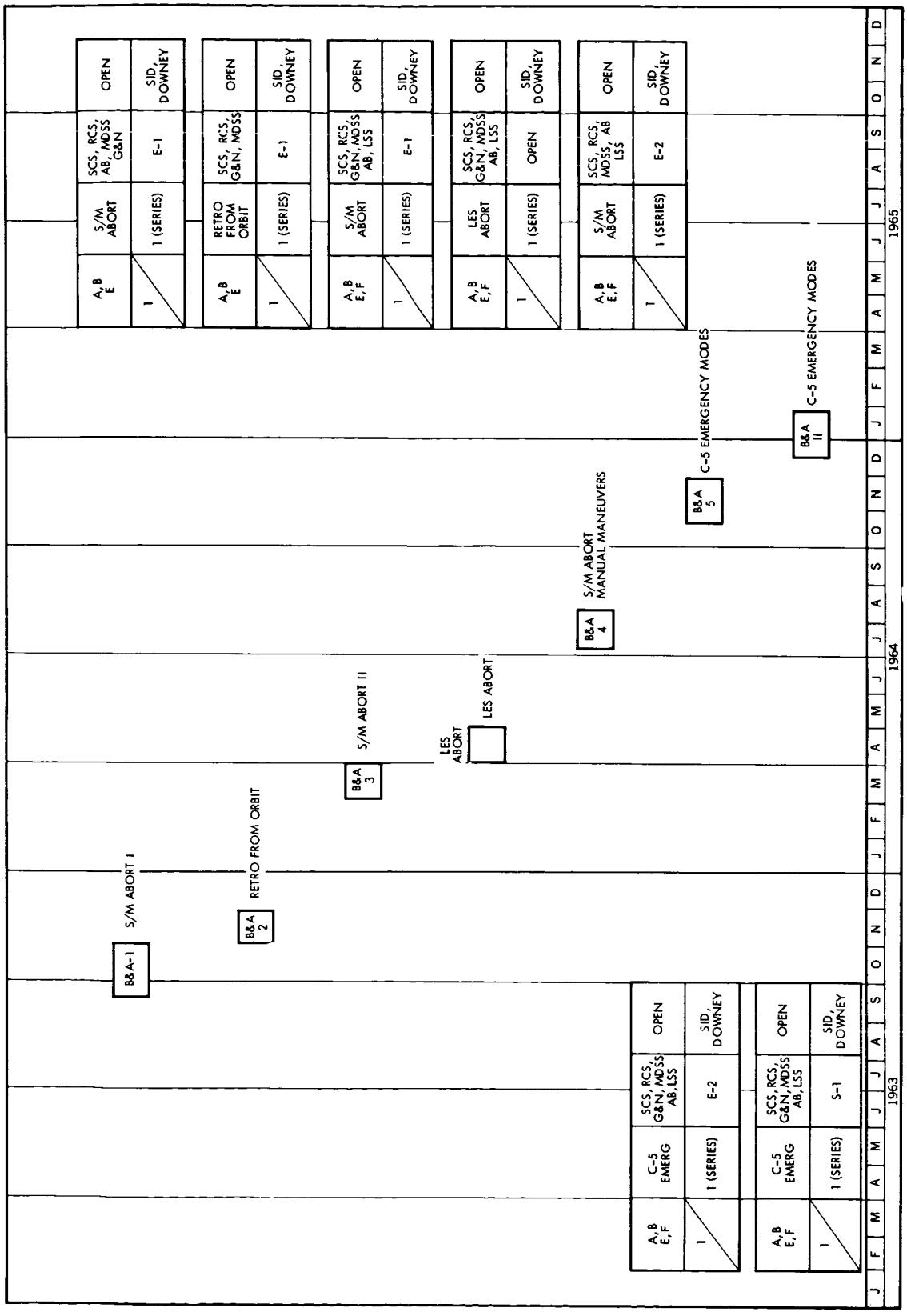

Figure 10-14. Mission Phases Boost and Abort Test Schedule

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10.3.1.1.2.2 Test Requirements.

10.3.1.1.2.2.1 Task.

1. Monitor displays during the critical phases of boost.
2. Initiate S/M abort sequence upon detecting a S/C systems failure.
3. Perform mode selection within required sequencing times.

10.3.1.1.2.2.2 Variables.

1. Pressure garment, pressurized versus nonpressurized
2. Malfunctions necessitating abort versus malfunctions in which abort is not necessary

10.3.1.1.2.2.3 Measurements.

1. Time required to detect possible abort situations
2. Time required to initiate abort sequence.

10.3.1.1.2.2.4 Design.

1. Schedule: To coincide with FP&C Boost and Abort Study No. 1. (September and October 1963).
2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.2.3 Equipment Requirements.

1. Vehicle: Evaluator E-1
2. Latest Apollo controls and displays
3. Pressure garment assembly
4. Crew couches
5. Communications
6. Video coverage

7. Computers: To be determined.

10.3.1.1.2.4 Facilities. S&ID facilities will be used.

10.3.1.1.3 Retro from Orbit. (Six DOF trajectory study for evaluation of overall system accuracy and operation for retro from earth orbit with both SPS and RCS).

10.3.1.1.3.1 Objectives.

1. Evaluate error involved in normal G&N and combined spacecraft systems dynamics during SPS powered retro from earth orbit.

2. Evaluate preentry dynamics (C/M - S/M separation maneuver) following normal retro from orbit.

3. Evaluate emergency modes for retro.

10.3.1.1.3.2 Test Requirements.

10.3.1.1.3.2.1 Tasks.

1. Monitor displays during critical phases of preentry.

2. Maneuver S/C to retro attitude and initiate retro sequence.

3. Initiate C/M - S/M separation.

10.3.1.1.3.2.2 Variables.

1. Pressure garment, pressurized versus nonpressurized

2. Various entry alignments

3. Various emergency conditions

10.3.1.1.3.2.3 Measurements.

1. Time required to detect a possible emergency situation

2. Time required to complete the retro sequence

3. Accuracy of preentry position

10.3.1.1.3.2.4 Design.

[redacted]

1. Schedule: To coincide with FP&C Study No. 2 (November 1963).

2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.3.3 Equipment Requirements.

1. Vehicle: E-1

2. Latest Apollo controls and displays

3. Pressure garment assembly

4. Crew couches

5. MDSS communications

6. Video coverage

7. Computers: To be determined.

10.3.1.1.3.4 Facilities. S&ID facilities will be used.

10.3.1.1.4 S/M Abort II. (Six DOF trajectory study to evaluate systems design for S/M abort, in terms of systems design compatibility and identification of electronic modes and manual or automatic procedures).

10.3.1.1.4.1 Objectives.

1. Evaluate the 6 DOF design compatibility of the G&N, SCS, and displays and controls for the tumbling environment of S/M abort.

2. Evaluate manual sequencing capabilities following abort.

3. Evaluate S/M - C/M separation maneuver, attitude orientation with and without S/C attitude reference.

10.3.1.1.4.2 Test Requirements.

10.3.1.1.4.2.1 Tasks.

1. Monitor displays during the critical phases of launch and boost.

2. Initiate S/M abort sequence upon detecting a critical S/C systems failure.

[redacted]

3. Initiate S/M - C/M separation and stabilize attitude.

10.3.1.1.4.2.2 Variables.

1. Tumbling rates
2. Pressure garment, pressurized versus nonpressurized
3. Various cues for C/M orientation
4. Manual versus automatic stabilization

10.3.1.1.4.2.3 Measurements.

1. Time to dampen tumbling
2. Time to reorient to entry angle
3. Position error in pitch, roll, and yaw
4. Fuel usage

10.3.1.1.4.2.4 Design.

1. Schedule: To coincide with FP&C, Boost and Abort Study No. 3 (March 1964).
2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.4.3 Equipment Requirements.

1. Vehicle: Evaluator E-L
2. Latest Apollo controls and displays
3. Pressure garment assembly
4. Crew couches
5. Communications
6. Video coverage

[redacted]

[redacted]

7. External earth horizon visual display

8. Sun shafting

9. Computers: To be determined.

10.3.1.1.4.4 Facilities. S&ID facilities will be used.

10.3.1.1.5 S/M Abort - Manual Maneuvers. (Six DOF trajectory study to evaluate maneuver capabilities for S/M abort).

10.3.1.1.5.1 Objectives.

1. Evaluate compatibility between EDS and S/M abort systems in terms of manual capabilities.

2. Evaluate task analysis abort procedural techniques.

3. Evaluate various decision-making aids and techniques for contingency operation.

10.3.1.1.5.2 Test Requirements.

10.3.1.1.5.2.1 Tasks.

1. Monitor displays during the critical phases of launch and boost.

2. Initiate S/M abort sequence upon detecting a critical S/C systems failure from C-1 Boost.

3. Initiate S/M - C/M separation and perform stabilizing maneuvers.

10.3.1.1.5.2.2 Variables.

1. Tumbling rates

2. Pressure garment, pressurized versus nonpressurized

3. Various cues for C/M orientation

4. Manual versus automatic stabilization

10.3.1.1.5.2.3 Measurements.

1. Time to dampen tumbling

[redacted]

[redacted]

2. Time to reorient to entry angle

3. Position error in pitch, roll, and yaw

4. Fuel usage

10.3.1.1.5.2.4 Design.

1. Schedule: To coincide with FP&C, Boost and Abort Study No. 4 (July, 1964).

2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.5.3 Equipment Requirements.

1. Vehicle: Evaluator E-2

2. Latest Apollo controls and displays

3. Pressure garment assembly

4. Crew couches

5. Communications

6. Video coverage

7. External earth horizon visual display

8. Sun shafting

9. Computers: To be determined.

10.3.1.1.5.4 Facilities. S&ID facilities will be used.

10.3.1.1.6 C-5 Emergency Modes. (A study of the use of spacecraft systems and operational techniques for maneuvers associated with aborts and spacecraft systems failures for the lunar mission).

10.3.1.1.6.1. Objectives.

1. Evaluate C-5 EDS and spacecraft compatibility.

2. Evaluate task analysis abort procedural techniques for C-5.

[redacted]

[redacted]

3. Evaluate S/M - C/M separation, maneuver, and attitude orientation.

10.3.1.1.6.2 Test Requirements.

10.3.1.1.6.2.1 Tasks.

1. Monitor displays during the critical phases of C-5 launch and boost.

2. Initiate S/M abort sequence upon detecting a critical S/C systems failure.

3. Initiate S/M - C/M separation and stabilize attitude.

10.3.1.1.6.2.2 Variables.

1. Tumbling rates

2. Pressure garment, pressurized versus nonpressurized

3. Various cues for C/M orientation

4. Manual versus automatic stabilization

10.3.1.1.6.2.3 Measurements.

1. Time required to dampen tumbling

2. Time required to reorient vehicle to the proper entry angle

3. Position error in pitch, roll, and yaw

4. Fuel usage

10.3.1.1.6.2.4 Design.

1. Schedule: To coincide with FP&C, Boost and Abort Study No. 5 (October and November, 1964).

2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.6.3 Equipment Requirements.

1. Vehicle: Evaluator E-2

[redacted]

2. Latest Apollo controls and displays

3. Pressure garment assembly

4. Crew couches

5. MDSS communications

6. Video coverage

7. External earth horizon visual display

8. Sun shafting

9. Computers: To be determined.

10.3.1.1.6.4 Facilities. S&ID facilities will be used.

10.3.1.1.7 C-5 Emergency Modes. (Six DOF simulation to evaluate the lunar vehicle design concept in terms of S/M abort and near-earth emergency maneuver requirements using prototype equipment).

10.3.1.1.7.1 Objectives.

1. Evaluate EDS and CSS suitability for emergency manual decision-making aids.

2. Evaluate extent to which external visual displays can be used to supplement S/C systems for abort situations.

3. Evaluate the interface of controls and displays with manual and automatic abort mechanization.

10.3.1.1.7.2 Test Requirement.

10.3.1.1.7.2.1 Tasks.

1. Monitor displays during the critical phases of C-5 launch and boost.

2. Initiate S/M abort sequence, upon detecting a critical S/C system failure.

3. Initiate S/M - C/M separation and stabilize attitude.

[redacted]

10.3.1.1.7.2.2 Variables.

1. Tumbling rates
2. Pressure garment, pressurized versus nonpressurized
3. Various cues for C/M orientation
4. Manual versus automatic stabilization

10.3.1.1.7.2.3 Measurements.

1. Time required to dampen tumbling
2. Time required to reorient vehicle to the proper entry angle
3. Position error in pitch, roll, and yaw
4. Fuel usage

10.3.1.1.7.2.4 Design

1. Schedule: To coincide with FP&C, Boost and Abort Study No. I (December 1964, January 1965).
2. Subjects: Number to be determined. All subjects will be trained to a performance plateau.

10.3.1.1.7.3 Equipment Requirements.

1. Vehicle: Simulator S-1
2. Latest Apollo controls and displays
3. Pressure garment assembly
4. Crew couches
5. MDSS communications
6. Video coverage
7. External earth horizon visual display
8. Sun shafting
9. Computers: To be determined.

10.3.1.1.7.4 Facilities. S&ID facilities will be used.

10.3.1.2 Coast and Maneuver Phase

10.3.1.2.1 Coast and Maneuver 1. (Five simulation to evaluate pilot's performance during earth and lunar orbit under SCS and G&N rotational modes.)

10.3.1.2.1.1 Objectives.

1. Evaluate pilot's performance using the SCS and G&N modes under various S/C weight/mass configurations during earth and lunar orbit.

2. Evaluate pilot's ability to perform attitude maneuvers utilizing visual displays.

3. Evaluate navigator techniques and proficiency while untilizing G&N equipment during earth and lunar orbit.

10.3.1.2.1.2 Test Requirements.

10.3.1.2.1.2.1 Task.

1. Maneuver the S/C from one attitude to another specified attitude in three axes by manipulating the attitude controller.

2. Operate the navigational sighting equipment to obtain earth and lunar landmark navigational sightings.

10.3.1.2.1.2.2 Variables.

1. S/C weight/mass configurations

2. Pressure garment, pressurized versus nonpressurized, versus constant wear garment

10.3.1.2.1.2.3 Measurements.

1. Fuel consumption for attitude maneuver

2. Accuracy of attitude maneuver with respect to final position

3. Time required for attitude maneuver

[redacted]

4. Accuracy of navigational sightings with respect to angular error

5. Rotational fuel consumed during the navigational sighting

6. Residual rates in x, y, and z axes at the moment of alignment

7. Time required for navigational sighting

10.3.1.2.1.2.4 Design.

1. Schedule: September, October 1963.

2. Subjects: To be determined.

10.3.1.2.1.3 Equipment Requirements.

1. Vehicle: E-2

2. C/M Interior:

   a. Latest Apollo design instrument panel

   b. Latest Apollo design attitude controller

   c. Pressure garment assembly, including provisions for vent air and/or breathing air

   d. Command Module communications system

   e. Breadboarded G&N system, including sextant and telescope

3. Special Equipment:

   a. Dynamic starfield

   b. Lunar-orbital landscape with several recognizable landmarks

   c. Earth-orbital landscape with several recognizable landmarks

4. Computers: Analog and digital computer tie-in

10.3.1.2.1.4 Facilities. S&ID facilities will be used

10.3.1.2.1.5 Test Schedule. The test schedule for the coast and maneuver phase is shown in Figure 10-15.

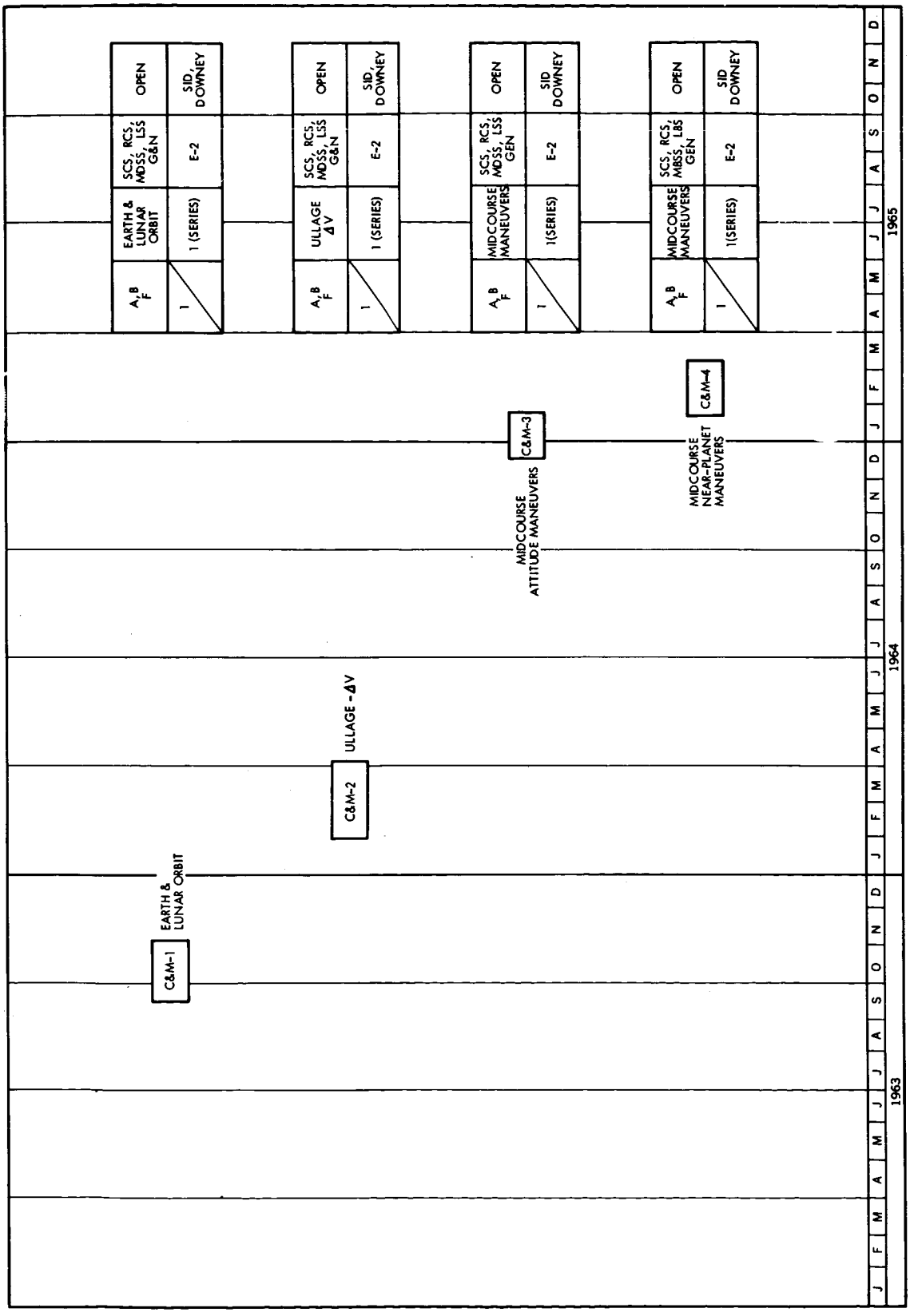

Figure 10-15. Mission Phases Coast and Maneuver Test Schedule

[redacted]

10.3.1.2.2 Coast and Maneuver 2. (A six-degree-of-freedom simulation study to evaluate pilot performance during lunar-orbit injection-transearth injection.)

10.3.1.2.2.1 Objectives.

1. Evaluate pilot's ability to perform maneuvers required for lunar-orbit injection and transearth injection.

2. Determine pilot's ability to determine ΔV requirements utilizing G&N sightings.

3. Determine pilot's ability to manually perform required ΔV maneuvers.

4. Determine pilot's ability to stabilize a tumbling spacecraft.

10.3.1.2.2.2 Test Requirements.

10.3.1.2.2.2.1 Task. Crewmen will be required to perform the following tasks:

1. Maneuver the spacecraft to take sightings of landmarks and celestial bodies.

2. Complete the computations required to provide trajectory injection information.

3. Manually perform any ullage and ΔV maneuvers required for lunar-orbit injection or transearth injection utilizing MDSS instructions.

4. Monitor and set the main panel displays and controls and manipulate the attitude and translational controllers.

10.3.1.2.2.2.2 Variables.

1. S/C weight/mass configuration (C/M + SM versus C/M + S/M + full LEM)

2. Various initial conditions

3. Hand controllers and display configurations

4. Pressure garment assembly (PGA) versus constant-wear garment (CWG)

[redacted]

10.3.1.2.2.2.3 Measurements.

1. Total fuel consumption for RCS and SPS
2. Accuracy of ΔV maneuvers from G&N, MDSS, and simulated AGC information
3. Time required to perform ΔV maneuvers
4. Errors in:
   a. Velocity
   b. Attitude
   c. ΔVelocity
   d. Gimbal angle settings
   e. Final attitude
5. Total time required for ΔV SPS firing
6. Number of RCS engine firings required to perform each attitude maneuver
7. RCS fuel consumption integrated with respect to time

10.3.1.2.2.2.4 Design.

1. Schedule: February, March 1963.
2. Subjects: To be determined.

10.3.1.2.2.3 Equipment Requirements.

1. Vehicle - Evaluator 2
2. C/M interior
   a. Latest Apollo design instrument panel and controls
   b. Latest Apollo design attitude and translational controls

[redacted]

[redacted]

c. Pressure garment assembly (pressurized and unpressurized), including provisions for vent air and/or breathing air.

d. Command Module communications system

3. Special equipment

a. Lunar horizon for tumbling stabilization

4. Computers: Analog and digital computer tie-in

10.3.1.2.2.4 Facilities. S&ID facilities will be used.

10.3.1.2.3 Coast and Maneuver 3. (A three DOF simulation to evaluate crew performance during translunar coast and transearth coast.)

10.3.1.2.3.1 Objectives.

1. Evaluate pilot's ability to perform midcourse attitude orientation maneuvers:

a. IMU alignment

b. Navigational sightings

c. Other attitude requirements

2. Evaluate navigator techniques and proficiency while utilizing G&N equipment during translunar coast and transearth coast.

10.3.1.2.3.2 Test Requirements.

10.3.1.2.3.2.1 Task.

1. Maneuver the S/C to take navigational sightings as required for IMU alignment.

2. Operate the navigational sighting equipment to obtain celestial fixes for IMU alignment.

10.3.1.2.3.2.2 Variables.

1. S/C weight/mass configurations

2. Pressure garment vented versus pressure garment pressurized, versus constant wear garment.

[redacted]

3. Minimum impulse and optics control configurations

4. Minimum impulse and optics control rates

5. Initial conditions of S/C and optics shaft and trunnion angles

6. Direct versus resolved mode for optics controller

7. Reticle configuration

8. Position of the mark button

10.3.1.2.3.2.3 Measurements.

1. Error in final attitude

2. Residual body axis drift

3. Angular error of navigational star fix

4. Time and fuel usage for attitude maneuvers prior to acquisition

5. Time and fuel usage for acquisition maneuvers using minimum impulse control and optics controller

6. Direction and number of pilot-induced erroneous commands

10.3.1.2.3.2.4 Design.

1. Schedule: December 1964, January 1965.

2. Subjects: To be determined.

10.3.1.2.3.3 Equipment Requirements.

1. Vehicle: Evaluator 2

2. C/M interior

   a. Latest Apollo design instrument panel and controls

   b. Latest Apollo design attitude controls

   c. Pressure garment assembly (pressurized and unpressurized) including provisions for vent air and/or breathing air

[redacted]

[redacted]

d. Command Module communication system

3. Special equipment.

a. Dynamic starfield

b. Telescope and sextant

c. Breadboarded G&N system

4. Computers: Analog and digital computer tie-in.

10.3.1.2.3.2.5 Facilities. S&ID facilities will be used.

10.3.1.2.4 Coast and Maneuver 4. (A six DOF simulation to evaluate crew performance during midcourse ΔV corrections.)

10.3.1.2.4.1 Objectives

1. Evaluate pilot performance and techniques in making ΔV corrections based on data derived from G&N, AGC, MDSS, and DSIF.

2. Evaluate pilot's ability to perform midcourse attitude orientation maneuvers under near planet conditions for:

a. Star-landmark sightings

b. IMU alignments

c. Other attitude requirements

3. Evaluate pilot's ability to manually perform ΔV correction.

10.3.1.2.4.2 Test Requirements.

10.3.1.2.4.2.1 Task.

1. Maneuver S/C to take navigational sightings required for IMU alignment.

2. Operate the navigational sighting equipment to obtain celestial fixes required for IMU alignment and trajectory corrections.

[redacted]

3. Compute requirements for and manually make TVC settings required to perform ΔV maneuver required for trajectory correction, utilizing data acquired from navigational sightings, MDSS, and DSIF.

10.3.1.2.4.2.2 Variables

1. S/C weight/mass configurations
2. Pressure garment vented versus pressure garment pressurized, versus constant wear garment
3. Minimum impulse and optics control configurations
4. Minimum impulse and optics control rates
5. Initial conditions of S/C attitude and of optics shaft and trunnion angles
6. Direct versus resolved mode for optics controller
7. Reticle configurations
8. Position of mark button

10.3.1.2.4.2.3 Measurements.

1. Final S/C attitude error
2. Residual body axis drift
3. Error in star-landmark alignment
4. Time and fuel required for attitude maneuvers prior to navigation sightings
5. Time required to accomplish navigational sighting using sextant, telescope
6. RCS fuel required during period of navigation sighting utilizing minimum impulse hand controller
7. Accuracy of TVC settings
8. Error in ΔV computations

9. SPS fuel required to perform ΔV maneuver

10.3.1.2.4.2.4 Design.

1. Schedule: January, February 1965.

2. Subjects: To be determined.

10.3.1.2.4.3 Equipment Requirements.

1. Vehicle: E-2

2. C/M Interior:

   a. Latest Apollo design instrument panel and controls

   b. Latest Apollo design attitude and translational controllers

   c. Pressure garment assembly including provisions for vent air and/or breathing air

3. Special Equipment.

   a. Dynamic starfield

   b. Telescope and sextant

   c. Near-earth visual display

   d. Far-earth visual display

   e. Near-moon visual display

   f. Far-moon visual display

   g. Breadboarded G&N system

4. Computers: Analog and digital computer tie-in.

10.3.1.2.4.4 Facilities. S&ID facilities will be used.

10.3.1.3 Entry Phase

10.3.1.3.1 Entry Simulation Study I. (Simulation and evaluation of orbital and suborbital reentry envelope SCS, RCS failure effects, with man in the loop.)

10.3.1.3.1.1 Objectives.

1. Determine possible problem areas resulting from interactions of the crew, controls, displays, entry profiles, and system contingencies.

2. Determine ability of the pilot to identify malfunctions in systems that will require emergency manual control of the C/M during the reentry phase.

3. Determine the ability of the pilot to properly control the roll attitude of the C/M while utilizing the manual and emergency manual system, during the reentry phase.

4. Evaluate the ability of the pilot to perform the necessary ELS procedure, and validate the task loading during critical reentry phases.

10.3.1.3.1.2 Test Requirements.

10.3.1.3.1.2.1 Tasks.

1. The pilot will monitor the displays and controls during the reentry phase, until contingency requires his activating the emergency manual override.

10.3.1.3.1.2.2 Variables

1. Different reentry angles

2. Contingencies

3. Shirt sleeve and space suit environment

10.3.1.3.1.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different levels

4. Reaction time

5. Amount of time trace is tangent or greater than tangent to the radial lines on the display

[redacted]

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

10.3.1.3.1.2.4 Design.

1. Schedule: Test series conducted by Flight Performance and Control (10 July 1963 to 1 September 1963)

2. Subjects: Subject criteria - astronaut proficiency.

10.3.1.3.1.3 Equipment Requirements.

1. Vehicle E-1

2. Roll indicator

3. FDAI

4. Rate needles

5. Rotational controller

6. Closed-circuit TV

7. X-Y plotter

8. Analog and digital computer with converters

9. 15 to 20 channel pen recorder

10.3.1.3.1.4 Facilities. S&ID facilities will be used.

10.3.1.3.1.5 Test Schedules. The entry simulation phase tests are shown in Figure 10-16.

10.3.1.3.2 Entry Simulation Study 2. (Simulation and evaluation of the entry monitor display, reorientation after tumbling, and SCS, RCS, G&N malfunction interaction during entry from orbital missions, with as astronaut in the loop)

10.3.1.3.2.1 Objectives.

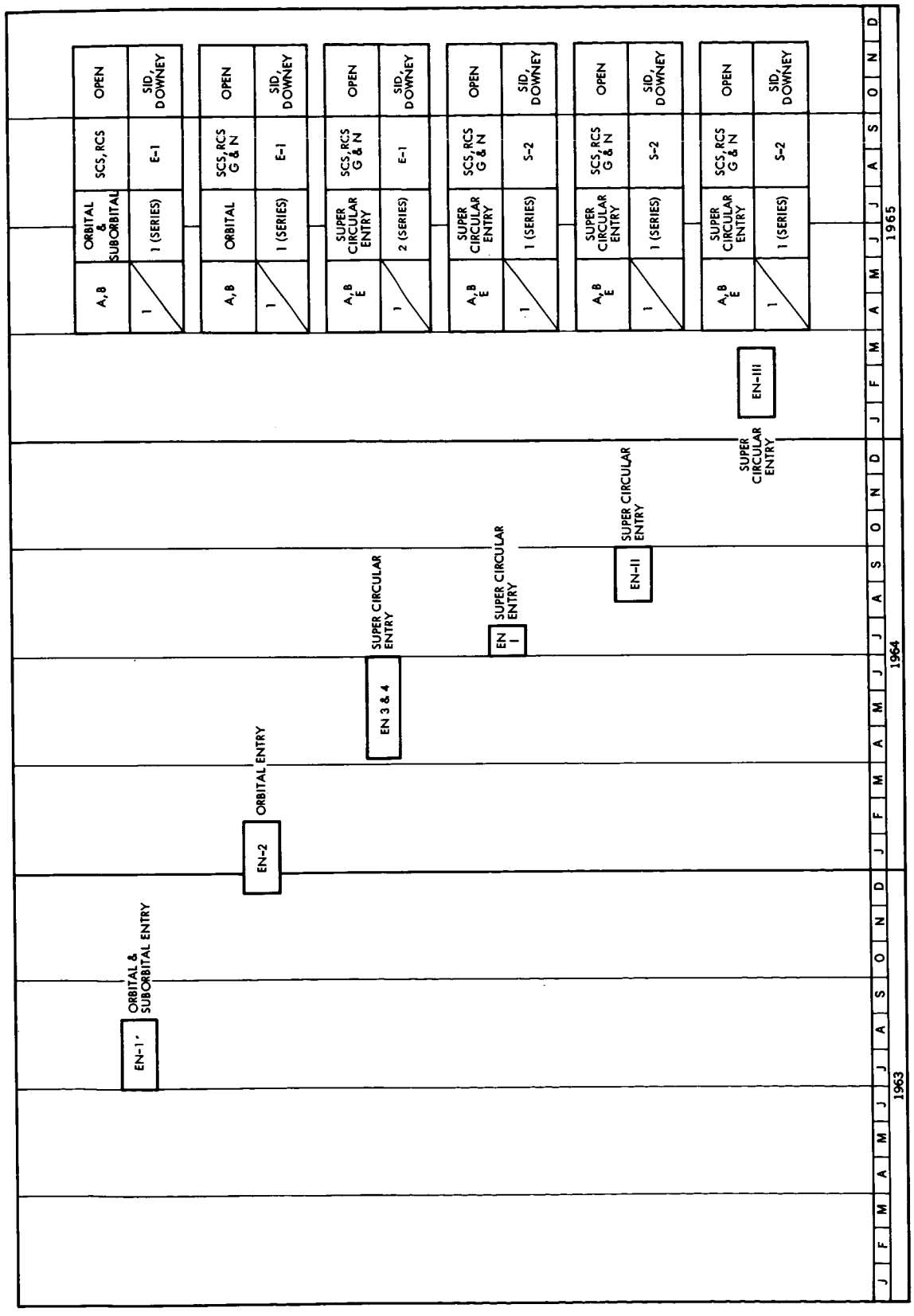

Figure 10-16. Mission Phases Entry Simulation Test Schedule

1. Evaluate G&N compatibility with other systems for reentry from an orbital mission with man in the loop.

2. Evaluate astronaut's ability to arrest tumbling and to reorient the C/M to proper entry attitude using updated displays and external visual cues.

3. Analyze failure effects and astronaut's capability to identify and manually override G&N commands when required to insure proper C/M orientation during reentry.

4. Determine RCS propellant consumption after failure effects requiring manual overriding by the astronaut.

5. Evaluate EMD-SCS-RCS compatibility and investigate the problem areas resulting from the Phase I centrifuge study conducted at Johnsville.

10.3.1.3.2.2 Requirements.

10.3.1.3.2.2.1 Task.

1. The pilot will monitor the displays and controls during the reentry phase until contingency requires his activating the emergency manual override.

10.3.I.3.2.2.2 Variables.

1. Different reentry angles

2. Contingencies

3. Shirt sleeve and space suit environments

4. Orientation by internal versus external displays

10.3.1.3.2.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different levels

4. Reaction time

5. Recorded history of G.V. (acceleration versus velocity) display

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

9. Time to properly orient C/M while tumbling

10.3.1.3.2.2.4 Design.

1. Schedule: Test series jointly conducted by FPC and L/S (15 December 1963 to 15 February 1964)

2. Subjects: Subject criteria - astronaut proficiency

10.3.1.3.2.3 Equipment Requirements

1. Vehicle E-1

2. Roll indicator

3. FDAI

4. Rate needles

5. Rotational controller

6. Closed circuit TV

7. X-Y plotter

8. Analog and digital computers with converters

9. 15-to-20-channel pen recorder

10.3.1.3.2.4 Facilities. S&ID facilities will be used.

10.3.1.3.3 Entry Simulation Study 3. (The simulation of a super-circular entry, evaluating the entry monitor display (EMD) in the automatic and manual mode with man in the loop)

10.3.1.3.3.1 Objectives.

[redacted]

1. Determine astronaut's ability to monitor a primary guidance entry using the EMD and accomplish manual override if required.

2. Evaluate redundancy and backup systems utilized by the astronaut while attempting reentry with a primary system malfunction requiring manual override.

3. Establish standardized procedures for maneuvering the C/M in the atmosphere following a preentry failure of the G&N.

4. Investigate the ability of the astronaut to extend the down-range landing site through the proper execution of an exit maneuver under manual control.

5. Evaluate the ability of the astronaut to orient the C/M for proper reentry attitude after a successful exit maneuver, with the aid of updated internal and external visual displays.

10.3.1.3.3.2 Test Requirements.

10.3.1.3.3.2.1 Task.

1. The pilot will monitor the displays and controls during the reentry phase until a contingency requires his activating the emergency manual override.

10.3.1.3.3.2.2 Variables.

1. Different entry angles

2. Contingencies

3. Shirt sleeve and space suit environment

4. Internal and external visual displays

10.3.1.3.3.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different levels

4. Reaction time

[redacted]IDENTIAL

5. Recorded history of G.V. display

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

9. Down-range landing site accuracy

10.3.1.3.3.2.4 Design.

1. Schedule: Test series jointly conducted by FPC and L/S (10 April 1964 to 1 July 1964)

2. Subjects: Subject criteria - Astronaut proficiency

10.3.1.3.3.3 Equipment Requirements.

1. Vehicle E-1

2. Roll indicator

3. FDAI

4. Rate Needles

5. Rotational controller

6. G.V. prototype display

7. Closed circuit TV

8. Analog and digital computers with converters

9. 15-to-20-channel pen recorders

10.3.1.3.3.4 Facilities. S&ID facilities will be used.

10.3.1.3.4 Entry Simulation Study 4. (A simulation for evaluating the overall systems performance, compatibility of the major systems (G&N, SCS, RCS, EMD) and astronaut, and the interaction of systems with various failures during automatic and manual modes during a supercircular entry)

10.3.1.3.4.1 Objectives.

1. Verify compatibility of the major entry flight systems (G&N, SCS, RCS, FDM) and astronaut for nominal and off-nominal automatic and manual supercircular entry conditions.

2. Evaluate the astronaut's ability to accomplish three-axes orientation of the C/M during exo-atmospheric maneuvers, and roll axis orientation of the C/M during atmospheric maneuvers using external visual cues.

10.3.1.3.4.2 Test Requirements.

10.3.1.3.4.2.1 Task.

1. The pilot will monitor the displays and controls during reentry phase until a contingency requires his activating the emergency manual override.

10.3.1.3.4.2.2 Variables.

1. Different entry angles

2. Contingencies

3. Internal and external visual cues

4. Shirt sleeve and space suit environment

10.3.1.3.4.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different levels

4. Reaction time

5. Recorded history of G.V. display

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

10.3.1.3.4.2.4 Design.

1. Schedule: Test series conducted by FPC (10 April 1964 to 1 July 1964)

2. Subjects: Subject criteria - astronaut proficiency

10.3.1.3.4.3 Equipment Requirements.

1. Analog computer

2. Digital computer

3. A/D and D/A converter

4. TV camera

5. Monitor (TV)

6. G. V. prototype display

7. X-Y plotter

8. Roll indicator

9. 3 caution lights (.05 g, -0 degree lift, -180 degree lift)

10. FDAI and rate indicators

11. Rotational controller

12. 15-to-20-channel pen recorder

13. Aural .05-g indicator

14. SCS control panel

15. IMU control panel

16. Gyro torque control panel

17. Mode select and adjust panel

18. Altimeter

19. Fuel indicator

20. RCS

21. EMD

22. G&N

23. Space suits and associated equipment

24. Vehicle - E-1

25. External displays for visual reorientation

10.3.1.3.4.4 Facilities. S&ID facilities will be used.

10.3.1.3.5 Entry Simulation Study I. (A simulation to evaluate pre-flight configuration and hardware compatibility, confirm previous entry simulation study results, and to re-evaluate potential problem areas identified in previous simulations which involved a man in the loop)

10.3.1.3.5.1 Objectives.

1. Provide thorough dynamic check and evaluation of prototype hardware with a man-in-the-loop environment.

2. Confirm any findings of previous entry simulation study results with man in the loop.

3. P -evaluate problem areas identified in previous manned entry simulations under man-in-the-loop environment.

10.3.1.3.5.2 Test Requirements.

10.3.1.3.5.2 1 Task.

1. The pilot will monitor the displays and controls during the reentry phase, until contingency requires his activating the emergency manual override.

10.3.1.3.5.2.2 Variables.

1. Different entry angles

2. Contingencies

3. Shirt sleeve and space suit environment

4. Internal versus external visual displays

10.3.1.3.5.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different levels

4. Reaction time

5. Recorded history of G.V. display

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

10.3.1.3.5.2.4 Design.

1. Schedule: Test series conducted by FPC (1 July 1964 to 20 July 1964)

2. Subjects: Subject criteria - astronaut proficiency

10.3.1.3.5.3 Equipment Requirements.

1. Vehicle - Simulator 2

2. Analog computer

3. Digital computer

4. A/D and D/A converters

5. TV camera

6. Monitor (TV)

[redacted]

7. G. V. prototype display
8. X-Y plotter
9. Roll indicator
10. 3 warning lights
11. FDAI and rate indicators
12. Rotational controller
13. 15-to-20-channel pen recorder
14. Aural .05-g indicator
15. SCS control panel
16. IMU control panel
17. Gyro torque control panel
18. Mode select and adjust panel
19. Altimeter
20. Fuel indicator
21. RCS
22. EMD
23. G&N
24. Space suits and associated equipment
25. External visual displays as necessary

10.3.1.3.5.4 Facilities. S&ID facilities will be used.

10.3.1.3.6 Entry Simulation Study II. (A manned simulation to evaluate AFRM 011 prototype flight hardware compatibility, confirm previous entry simulation study results, and to re-evaluate potential problem areas identified in previous simulations with man in the loop)

[redacted]

10.3.1.3.6.1 Objective.

1. Provide a thorough dynamic check and evaluation of prototype flight hardware from a L/S point of view with a man in the loop environment.

2. Confirm previous AFRM 011 manned entry simulation study results.

3. Re-evaluate potential problem areas identified in previous simulations.

4. Investigate the effects of hardware, G&N characteristics, and man-in-the-loop interaction on overall system performance during reentry.

5. Confirm astronaut's ability to perform all operations flight tasks during orbital entry.

10.3.1.3.6.2 Test Requirements.

10.3.1.3.6.2.1 Task

1. The pilot will monitor the displays and controls during the entry phase, until contingency requires his activating the emergency manual override.

10.3.1.3.6.2.2 Variables.

1. Different entry angles

2. Contingencies

3. Shirt sleeve and space suits

4. Internal and external visual displays

10.3.1.3.6.2.3 Measurements.

1. Maximum g's

2. G - onset

3. G - duration at different angles

[redacted]

4. Reaction time

5. Amount of time trace is tangent to or greater than tangent to the radial lines on the display.

6. Tracing of roll position at all times

7. Total fuel consumption

8. Manual attitude control accuracy

10.3.1.3.6.2.4 Design.

1. Schedule: Test series conducted by FPC (15 August 1964 to 1 October 1964)

2. Subjects: Subject criteria - astronaut proficiency

10.3.1.3.6.3 Equipment Requirements.

1. Vehicle - Simulator 2

2. Analog computer

3. Digital computer

4. A/D and D/A converters

5. TV camera

6. Monitor (TV)

7. Rotational controller

8. 15-to-20-channel pen recorder

9. Aural .05-g indicator

10. SCS prototype hardware

11. RCS prototype hardware

12. EMD prototype displays

[redacted]

13. IMU control panel

14. Gyro torque control panel

15. Mode select and adjust panel

16. Altimeter

17. Fuel indicator

18. Space suit and associated equipment

10.3.1.3.6.4 Facilities. S&ID facilities will be used.

10.3.1.3.7 Entry Simulation III. (A manned entry simulation of the hardware compatibility and the evaluation of all entry flight systems under simulated supercircular entry conditions to insure incorporating any required Life Systems design changes)

10.3.1.3.7.1 Objectives.

1. Provide a thorough dynamic check and evaluation of prototype hardware with man in the loop.

2. Investigate effects of hardware G&N characteristics on overall system performance during supercircular entry with man in the loop.

3. Verify astronaut's capability to perform all operational tasks during supercircular entry.

4. Verify previous simulation study results.

5. Re-evaluate potential problem areas identified in previous simulations with man in the loop.

10.3.1.3.7.2 Test Requirements.

10.3.1.3.7.2.1 Task.

1. The pilot will monitor the displays and controls during the reentry phase until contingency requires his activating the emergency manual mode.

[redacted]

[redacted]

10.3.1.3.7.2.2 Variables.

1. Different reentry angles
2. Contingencies
3. Shirt sleeve and space suits
4. Internal and external visual cues

10.3.1.3.7.2.3 Measurements.

1. Maximum g's
2. G - onset
3. G - duration at different angles
4. Reaction time
5. Amount of time trace is tangent to or greater than tangent to the radial lines on the display.
6. Tracing of the roll position at all times
7. Total fuel consumption
8. Manual attitude control accuracy

10.3.1.3.7.2.4 Design.

1. Schedule: Test series conducted by FPC (20 January 1965 to 15 March 1965)
2. Subjects: Subject criteria - astronaut proficiency

10.3.1.3.7.3 Equipment Requirements.

1. Vehicle - Simulator 2
2. Analog computer
3. Digital computer

4. A/D and D/A converters
5. TV camera
6. Monitor (TV)
7. G. V. prototype display
8. Roll indicator
9. 3 warning lights
10. FDAI and rate indicators (prototype)
11. Rotational hand controller
12. 15 to 20 channels
13. Aural .05-g indicator
14. SCS panel (prototype)
15. IMU control panel (prototype)
16. Gyro torque control panel (prototype)
17. Mode select and adjust panel (prototype)
18. Altimeter (prototype)
19. Fuel indicator (prototype)
20. RCS (prototype)
21. EMD (prototype)
22. G&N (prototype)
23. Space suits and associated equipment (prototype)

10.3.1.3.7.4 Facilities. S&ID facilities will be used.

[redacted]

10.3.2 Dynamic Base

10.3.2.1 Manned Centrifuge Study, Phase I

(Evaluation of Apollo design parameters by assessment of crew performance during launch, abort and entry acceleration) Dy-2

10.3.2.1.1 Objectives.

1. Evaluate ability of crew to monitor systems during normal launch profiles; evaluate ability of pilot to initiate abort during launch profiles.

2. Evaluate ability of crew members to perform manual overrides during and following abort profiles.

3. Evaluate ability of crew members to perform manual mode entry tracking during entry profiles.

4. Evaluate crew support system and restraint harness during acceleration profiles.

5. Evaluate crew abilities (above) while wearing ventilated pressure garment assembly (Class III).

10.3.2.1.2 Test Requirements.

10.3.2.1.2.1 Tasks. Crew members will:

1. Monitor systems during launch.

2. Initiate pad, max-Q, and high-altitude abort.

3. Perform manual overrides on LES.

4. Perform manual overrides on ELS.

5. Perform manual mode entry tracking.

10.3.2.1.2.2 Variables.

1. "Worst case" entry profiles

2. Various abort profiles (pad, max-Q, high-altitude)

3. Crew couch adjustments

10.3.2.1.2.3 Measurements.

1. Ability and time required to initiate manual abort

2. Efficiency of manual overrides during acceleration profiles

3. Accuracy of entry tracking (manual mode)

4. Monitoring efficiency

5. Physiological monitoring

6. Crew couch and restraint characteristics

10.3.2.1.2.4 Design.

1. Schedule:

   a. Begin Johnsville installation 1 September 1963.

   b. Begin data runs 1 October 1963.

2. Subjects: NASA furnished astronauts (six).

10.3.2.1.3 Equipment Requirements. NAA furnished test fixture to be installed in Johnsville AMAL centrifuge gondola. Fixture contains framework, instrument panel, handcontrollers, couch and restraint system, as well as NASA furnished ventilation system, pressure garment assembly (Class III), biomedical monitoring instrumentation, and monitoring TV camera.

10.3.2.1.4 Facilities. The Johnsville, Pa., AMAL, NADC Centrifuge Facilities will be used.

10.3.2.1.5. Test Schedule. The manned centrifuge study test schedule is shown in Figure 10-17.

10.3.2.2 Centrifuge, Phase II, Test A, Boost and Abort

(Simulation and evaluation of commander's displays and controls necessary under acceleration and vibration profiles) Dy-3

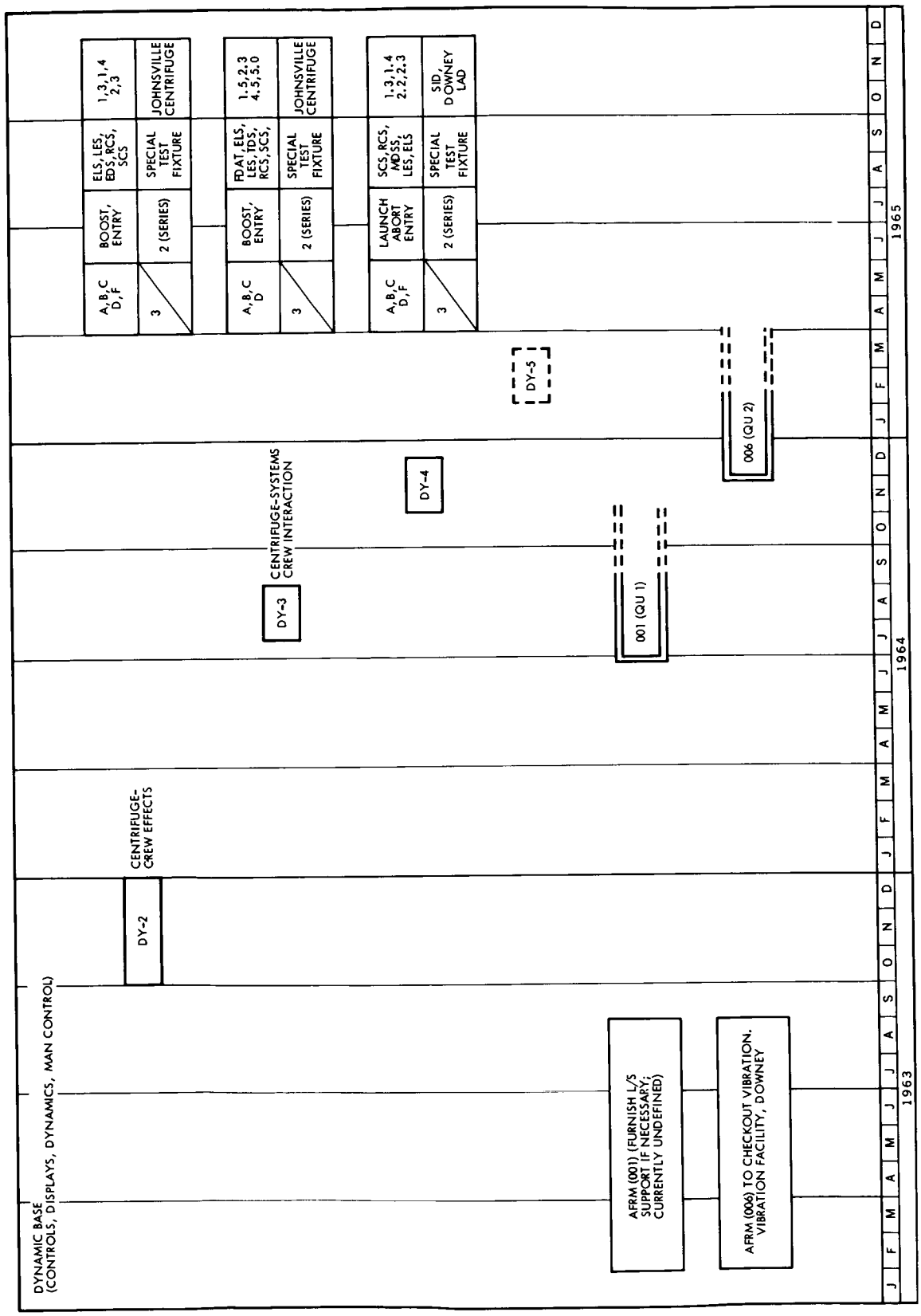

Figure 10-17. Manned Centrifuge Study Test Schedule

[redacted]

10.3.2.2.1 Objectives.

1. Evaluate ability of crewman to detect and make decisions concerning situations which may lead to abort.

2. Evaluate ability of crewman to perform manual and manual backup abort and postabort procedures using the following profiles:

   a. Pad abort

   b. Max-Q abort

   c. High-altitude abort

3. Evaluate ability of crewman to communicate during boost and abort.

4. Evaluate ability of crewman to perform visual monitoring during boost and abort.

5. Evaluate ability of crewman to perform all boost and abort functions in a 5-psia, 100-percent oxygen environment, under acceleration and vibration profiles and under suit pressures of 3.5 psia.

6. Evaluate Apollo design, including couch, displays, controls, lighting, and personal communication assemblies.

10.3.2.2.2 Test Requirements.

10.3.2.2.2.1 Tasks. The crewman will be required to perform the following tasks:

1. Monitor the emergency detection system (EDS), FDAI, LES, caution lights, warning lights (with auditory signal) and abort light, and make appropriate response.

2. Maintain MDSS communications.

3. Initiate abort sequence dependent on MDSS instrumentation or own initiative, dependent on contingency.

10.3.2.2.2.2 Variables.

1. Automatic versus manual versus manual backup aborts

[redacted]

[redacted]

2. Pressure garment assembly (Class III) pressurized versus non-pressurized

3. Go versus no go instrument indications

4. Communications versus loss of communications

5. Vibration versus nonvibration

10.3.2.2.2.3 Measurements.

1. Time required to detect possible abort situation

2. Time required for abort decision making (GO - NO GO)

3. Time required to initiate abort

4. Physiological data for analysis

5. Accuracy of decision to abort (or not abort)

10.3.2.2.2.4 Design.

1. Schedule: 1 April 1964 to 1 June 1964

2. Subjects: Six astronaut subjects will be used

10.3.2.2.3 Equipment Requirements.

1. Special test fixture

2. Crew couch and restraints

3. Pressure garment assembly (Class III).

4. 5-psia, 100-percent O_2 environment

5. Biomedical instrumentation

6. Motion picture and TV cameras

7. The following displays and controls:

   a. LES display and control

   b. FDAI

[redacted]

c. C/M communications system

d. Lighting controls

e. Caution indicators

f. Warning indicators

g. Abort indicator

h. Abort lever

i. Translational controller for abort

j. Latest Apollo attitude controller

k. I. C. stop button

8. Computers: As specified in SID 62-1303, 1. 5, 2. 3, 4. 5, 5. 0 and as available at N. A. D. C., Johnsville, Pa.

10. 3. 2. 2. 4 Facilities. The N. A. D. C. Centrifuge at Johnsville, Pa. will be used.

10. 3. 2. 3 Centrifuge, Phase II, Test B, Entry. Dy-3

10. 3. 2. 3. 1 Objectives.

1. Evaluate ability of crewman to perform visual monitoring during entry with a vibration spectrum imposed on entry acceleration under 5-psia, 100-percent O_2 environment

2. Evaluate ability of crewman to communicate during entry profiles of vibration, acceleration 5-psia, 100-percent environment.

3. Evaluate ability of crewman to operate necessary manual and emergency override controls to maintain proper entry envelope under conditions of vibration, ambient noise acceleration, and 5-psia, 100-percent O_2 environment.

4. Evaluate commander-controlled entry profiles.

10. 3. 2. 3. 2 Test Requirements.

10. 3. 2. 3. 2. 1 Tasks. The crewman will be required to perform the following tasks:

[redacted]

1. Monitor the FDAI, entry monitoring indicator, caution and warning lights.

2. Maintain MDSS communications.

3. Maintain proper entry envelope when in manual mode.

10.3.2.3.2.2 Variables.

1. Automatic versus manual versus emergency override control

2. Pressure garment assembly (Class III) pressurized versus non-pressurized

3. Minimum entry angle versus maximum entry angle versus midpoint entry angle

10.3.2.3.2.3 Measurements.

1. Amount of fuel and time required to accomplish successful entry under emergency conditions

2. Efficiency of manual entry performance

3. G loading imposed by maneuver

4. Physiological data for analysis

10.3.2.3.2.4 Design

1. Schedule: 1 April 1964 to 1 June 1964.

2. Subjects: 6 astronaut subjects will be used, each individually tested.

10.3.2.3.3 Equipment Requirements. Same as Test A plus entry monitoring indicator and SCS control and display.

1. Computers: As specified in SID 62-1303, 1.5, 2.3, 4.5, 5.0 and by the Naval Air Development Center, Johnsville, Pa.

10.3.2.3.4 Facilities. The N. A. D. C. Centrifuge at Johnsville, Pa. will be used.

[redacted]

10. 3. 2. 4 Vibration and Noise Level Crew Effects Tests

(Evaluate abilities of crew related to monitoring and manual override duties.) Dy-4

10. 3. 2. 4. 1 Objectives.

1. Evaluate crew performance decrements in monitoring display information required during launch, abort, and entry oscillation.
2. Evaluate ability of crew to initiate abort during boost oscillations within design limits.
3. Evaluate capability of crew to perform all necessary manual overrides following abort oscillations.
4. Evaluate ability of crew to perform tracking in manual mode of entry.
5. Determine adequacy of speech intelligibility in crew communications during launch and entry oscillation periods.
6. Assess crew support system to provide satisfactory vibration isolation.

10. 3. 2. 4. 2 Test Requirements.

10. 3. 2. 4. 2. 1 Tasks.

1. Subjects shall monitor displays during launch oscillation.
2. Subjects shall be required to initiate abort.
3. Subjects will perform all manual LES and ELS overrides following abort vibration.
4. Subjects shall perform manual tracking during entry oscillation.
5. Crew shall communicate with "MDSS" during all mission vibration profiles.

10. 3. 2. 4. 2. 2 Variables.

1. Incorporation of C/M dynamic vibration equations for launch, abort, and entry
2. Pressurized versus unpressurized suit conditions

[redacted]

10. 3. 2. 4. 2. 3 Measures.

1. Visual perception of display information during launch, abort, and entry vibration

2. Ability of crew to initiate abort during launch oscillation

3. Efficiency of required manual overrides

4. Accuracy of entry tracking

5. Intelligibility of crew verbal transmissions

6. Vibration intensity levels recorded on crew members

10. 3. 2. 4. 2. 4 Design. Each of the objectives above will be investigated in separate tests in order to provide meaningful data. This is necessary because, for example, normal launch cannot be continued beyond abort situation. Specific designs for each test, therefore, are in process of development.

1. Subjects: A full crew will be employed, each subject being run in each duty station.

10. 3. 2. 4. 3 Equipment Requirements

1. Vehicles: Special test fixture incorporating a complete spacecraft crew support system and vibration-proof panel will be utilized. The fixture will be rigidly mounted on a shake table and driven in three axes (X, Y, and Z).

2. Displays - Controls:

   a. Hand controllers on couch arm

   b. Display panel complete with major displays (ELS, LES, EDS, event timer, SCS, RCS, entry analog, PUCS, etc.)

   c. Communications

3. Computers: Analog computer tie-in

10. 3. 2. 4. 4 Facilities. S&ID facilities will be used.

[redacted]

10. 3. 2. 5 S/C Tumbling Simulation

(Stabilization of C/M during tumbling induced by mission abort - pad abort, max-Q abort, and high-altitude abort, – using C/M RCS manual and automatic modes) Dy-5. This test will be conducted only if boilerplate shots indicate excessive torque is induced in C/M on abort.

10. 3. 2. 5. 1 Objectives.

1. Evaluate crew couches and restraint systems under various tumbling situations.

2. Evaluate crew ability using emergency manual mode of SCS to stabilize C/M when tumbling.

3. Evaluate crew performance using various displays and external visual cues required to stabilize tumbling and assume entry attitude.

4. Evaluate crew ability to maintain proper entry attitude after stabilizing tumbling.

10. 3. 2. 5. 2 Test Requirements.

10. 3. 2. 5. 2. 1 Task. The tasks are composed of a combination of simultaneous pitch, yaw, and roll rates which must be nulled by the subject. He must then reorient C/M to entry angle.

10. 3. 2. 5. 2. 2 Variables.

1. Various mission phase aborts

2. Various tumbling torque rates

3. Various crew restraint systems

4. Various cues for C/M orientation

5. Manual versus automatic stabilization

10. 3. 2. 5. 2. 3 Measurements.

1. Effectiveness of crew restraint system with respect to affording crew ample protection and freedom of hand and head movements, required to control C/M.

[redacted]

2. Roll, pitch, and yaw position with respect to desired positions and initial rates.

3. Integrated yaw, pitch, and roll errors of absolute position from desired position to 2 degree deadband

4. Time to dampen tumbling

5. Time to reorient to entry angle

10. 3. 2. 5. 2. 4 Design.

1. Schedule: 80 hours - 8 hours per day each subject to serve 2 hours per day.

2. Dates: To be determined at a later date.

3. Subjects: Four pilot subjects (to run one at a time).

10. 3. 2. 5. 3 Equipment Requirements.

1. C/M interior:

   a. Latest Apollo design controls and displays

   b. MDSS communications

   c. Pressure garment assembly (Class III)

   d. Crew couches and restraint systems

   e. Motion picture and TV cameras

2. Simulated earth horizon

3. Vehicle: Special test fixture

4. Computers: To be determined at a later date.

10. 3. 2. 5. 4 Facilities. The facilities to be used will be determined at a later date.

10. 3. 3 Qualification Testing

10. 3. 3. 1 AFRM 006 Vibration and Acoustics Test Vehicle QU 006

[redacted]

This vehicle is one in which qualification testing with acoustics and vibration will be accomplished.

The primary objective of life systems testing is that of verifying that the crew will be isolated from:

1. Acoustic levels detrimental to the crew
2. Vibration levels greater than statement of work limits
3. Vibration levels which jeopardize satisfactory crew performance

Instrumentation (primarily accelerometers) will be attached to the crew and crew support systems in order to record dynamic levels.

Limited performance data will be collected for correlation with those obtained from vibration tests in the Dy series.

10. 3. 3. 2 AFRM 008 Environmental Proof Tests QU 008

10. 3. 3. 2. 1 Objectives. Verify all spacecraft systems and their man-machine interactions with particular emphasis on the following:

1. Verify the ability of the crew to use the manual mode of operation under emergency conditions.
2. Verify physiological effects on the crew as a result of the C/M interior environment (i. e., pressure gaseous, temperature), limited metabolic evaluations, contaminant effects, and solar radiation (filters).
3. Verify the sanitation system.
4. Verify the food and water provisions.
5. Verify the adequacy and capabilities of the bioinstrumentation.
6. Appraise crew tasks.
7. Appraise displays and controls.
8. Verify ECS operation and management.
9. Verify work-rest cycle, if 7- or 14-day test is conducted.
10. Evaluate in-flight maintenance tasks.

[redacted]

10. 3. 3. 2. 2 Test Requirements

10. 3. 3. 2. 2. 1 Tasks. Crewmen will be required to operate the spacecraft systems under simulated environmental conditions during the following phase:

Phase I Earth Orbital Qualification

1. Prelaunch
2. Boost
3. Separation
4. Earth orbit
5. Reentry.

10. 3. 3. 2. 2. 2 Variables.

1. Cabin temperature, pressure, and gaseous content
2. Control stresses under a hard vacuum
3. Pressure garment assembly (Class III) environment

10. 3. 3. 2. 2. 3 Measurements.

1. Crew physiological reactions
2. Pressure garment assembly versus "shirt-sleeve" crew performance with respect to time and/or accuracy
3. Time required for crew to evaluate the environment of the C/M during a simulated malfunction

10. 3. 3. 2. 2. 4 Design.

1. Schedule: Life Systems requirements for AFRM 008 tests will be accomplished concurrently with all or part of the AFRM 008 Environmental Proof test program (Reference Volume V).
2. Subjects: Three astronauts will be used. Subjects will operate as an integrated crew.

[redacted]

10. 3. 3. 2. 3 Equipment Requirements.

1. Cabin interior:

   a. S/C displays and controls

   b. S/C crew couches

   c. Pressure garment assembly (Class IV)

   d. S/C food, water, and waste management

   e. S/C ECS

   f. MDSS communication

2. Vehicle: AFRM 008.

3. Computers: Refer to SID 62-1303, 5. 2, and SID 62 PI-695-420-1, 8. 1.

10. 3. 3. 2. 4 Facilities. The MSC facilities at Houston will be used.

10. 3. 4 Crew Integration

10. 3. 4. 1 Critical Phases - Crew Integration

(Examination of interrelationship of tasks with specific emphasis on work load, task allocation, and displays and controls) In-1

10. 3. 4. 1. 1 Objectives.

1. Evaluate crew performance on integrated tasks such as:

   a. Navigational fixes and ΔV corrections

   b. Docking

   c. Ball (FDAI) and IMU alignment

2. Validate work loading.

3. Validate task allocation.

4. Evaluate the effects of equipment design and functional arrangements on the performance of crew integrated tasks.

5. Evaluate integrated communication between:

   a. Crew members

   b. C/M and MDSS

   c. C/M and LEM

10.3.4.1.2 Test Requirements.

10.3.4.1.2.1 Tasks. Crewmen will be required to perform the following:

1. Take navigational sightings and make ΔV correction as an integrated crew task.

2. C/M crew support of LEM in performing transposition and docking procedures as an integrated crew function.

3. Perform ball (FDAI) IMU alignment as an integrated crew task.

4. C/M support of LEM (simulated) mission.

5. Crew communication with MDSS.

6. Orient high-gain antenna.

10.3.4.1.2.2 Variables.

1. Task allocation

2. Variable star field

3. Control and display arrangement

10.3.4.1.2.3 Measurements.

1. Time period required to perform integrated tasks such as:

   a. Navigational fixes

   b. Docking

   c. Ball alignment

   d. Etc.

2. The proficiency with which the above tasks are performed as an integrated task.

10.3.4.1.2.4 Design.

1. Schedule: 1 May 1964 to 1 June 1964.

2. Subjects: Three pilot subjects will be used. Subjects will operate as an integrated crew, completing a specific number of runs per variable at each crew position. NASA has indicated the possibility of utilizing astronauts as subjects.

10.3.4.1.3 Equipment Requirements.

1. Vehicle: E-5

2. C/M Interior:

   a. Latest available Apollo design displays and controls (including G&N)

   b. FDAI including rate meters

   c. Crew couches

   d. Pressure garment assembly (Class III (3)

   e. Communications

   f. Star field

3. External: Simulated MDSS and LEM communications

4. Computer: Requirements as stated in SID 62-1303, 2.2, 4.1, 4.2.

10.3.4.1.4 Facilities. S&ID facilities will be used.

10.3.4.1.5 Test Schedule. The crew integration test schedule is shown in Figure 10-18.

10.3.4.2 Critical Phases and Contingencies - Crew Integration.

(Examination of interrelationship of tasks with specific emphasis on work load, task allocation, and displays and controls under emergency conditions) In-2

10.3.4.2.1 Objectives.

1. Evaluate crew interaction during critical flight phases.

2. Evaluate crew interaction during emergency conditions.

3. Evaluate possible task overloadings.

4. Evaluate the effects of equipment design and functional arrangements on the performance of crew integrated tasks.

5. Evaluate the ability of the crew to determine system malfunctions and the time and procedure required to correct the malfunction.

10.3.4.2.2 Test Requirements.

10.3.4.2.2.1 Tasks (Performed as an integrated crew)

1. Perform the following:

   a. Navigational sightings and ΔV maneuvers

   b. Transposition and docking

   c. FDAI and IMU alignment

   d. Abort with critical system(s) failure

   e. Entry with critical system(s) failure

2. Appraise system malfunctions and determine and perform corrective procedures.

3. Perform necessary MDSS communication and consultation during normal and emergency conditions.

4. Monitor and communicate system verifications among crew members and with MDSS.

Note: Specific task allocation of integrated tasks will be incorporated upon their receipt from task analyses.

10.3.4.2.2.2 Variables.

1. Task allocation

2. Variable star field

3. Control and display arrangement

4. Contingencies

10.3.4.2.2.3 Measurements.

1. Time required to detect and correct system malfunction

2. The proficiency with which the system malfunction is corrected

3. Validate task allocation.

4. Proficiency with which integrated tasks are performed

5. Time required to perform integrated tasks

10.3.4.2.2.4 Design.

1. Schedule: 1 September 1964 to 15 October 1964.

2. Subjects: Three pilot subjects will be used. Subjects will operate as an integrated crew, completing a specific number of runs per variable at each crew position. (NASA has indicated the possibility of utilizing astronauts as subjects.)

10.3.4.2.3 Equipment Requirements.

1. Vehicle: S-1

2. C/M Interior: Latest Apollo design - displays and controls (hardware checkout)

3. External simulated MDSS and LEM communications

4. Computers: Requirements as stated in SID 62-1303, 2.2, 4.1 and 4.2.

10.3.4.2.4 Facilities. S&ID facilities will be used.

10.3.5 Habitability - Environment

10.3.5.1 Earth Orbit Habitability

(Evaluation of crew habitability and performance during simulated earth orbital mission) Ha-1

10.3.5.1.1 Objectives.

Primary

1. Dietary development
2. Evaluate food and waste management, food packaging and personal hygiene procedures.
3. Evaluation of physiological phenomena
4. Determine biological control requirements.
5. Evaluation of total metabolic balance
6. Evaluation of medical equipment
7. Evaluation of crew equipment (approximately ten items)
8. Evaluation of personal communication equipment and problems

Secondary

1. Evaluate crew performance on Apollo integrated tasks.
2. Evaluate work-rest cycle and task loadings.
3. Evaluation of crew performance while in pressure garment assembly (unpressurized, ventilated)
4. Evaluation of displays and controls operation

10.3.5.1.2 Test Requirements.

10.3.5.1.2.1 Task. Crew will operate on 4-hour duty periods alternating between the right and left hand couches, and an 8-hour sleep period. There will be two men on duty at all times, with the exception of the prelaunch, launch, and entry phases, during which times all three subjects will be on duty. (A nonpressurized, ventilated spacesuit may be worn by the subject in the control position - left-hand couch.) The vehicle contains an Apollo breadboard main displays and controls panel and simplified G&N equipment. Stabilization and control system tasks, caution light monitoring, G&N tasks, simplified in-flight maintenance tasks, and emergency indications will be programmed for action by the subjects on duty. Subjects will communicate with simulated MDSS personnel. Dehydrated food diet will be provided. Physiological measurements will be made throughout.

[redacted]

10.3.5.1.2.2 Variables.

1. Duty periods; days.

10.3.5.1.2.3 Measurements.

1. Efficiency of warning light monitoring (reaction time, correct or incorrect response)

2. Number of warning indicator conditions detected on panel

3. Accuracy of tracking

4. Accuracy of G&N task performance

5. Physiological measures include:

   a. Blood pressure and oral temperature every 8 hours

   b. EKG approximately every 3 days

   c. Blood samples every 4 days

   d. Microbial samples from crew daily, from equipment every 3 days

   e. Ambient temperature and relative humidity readings

10.3.5.1.2.4 Design.

1. Schedule: Undetermined.

2. Subjects: Three pilot subjects, three simulated mission data support system (MDSS) personnel.

10.3.5.1.3 Equipment Requirements.

1. Vehicle: Equipped life systems evaluator (crew systems analyzer).

2. C/M Interior:

   a. Breadboard main displays and controls panel

   b. Simplified G&N equipment

[redacted]

[redacted]

c. Crew couches

d. Life support provisions

e. Communications equipment

f. Personal hygiene and medical monitoring equipment

g. Lapboard and log book assemblies

h. Miscellaneous hardware

3. Special test equipment:

a. Crew systems test console

b. Pressure garment assembly

4. Computers: No additional tie-in required.

10.3.5.1.4 Facilities. S&ID facilities will be used.

10.3.5.1.5 Test Schedule. Habitability test schedules are shown in Figure 10-18.

10.3.5.2 One-Man Emergency Earth Return.

(Evaluation of habitability and performance during simulated transearth injection and transearth coast mission alone) Ha-2. Reference: SID 52-1303, 4.2

10.3.5.2.1 Objectives.

1. Evaluate one man performance on Apollo integrated tasks.

2. Evaluate task and work-rest schedule. (Evaluate performance decrements accompanying irregular sleep and duty periods.)

3. Evaluate food and waste management and personal hygiene procedures under extended duty conditions.

4. Evaluate physiological condition of crewman.

5. Evaluate display and control arrangement for one-man operation.

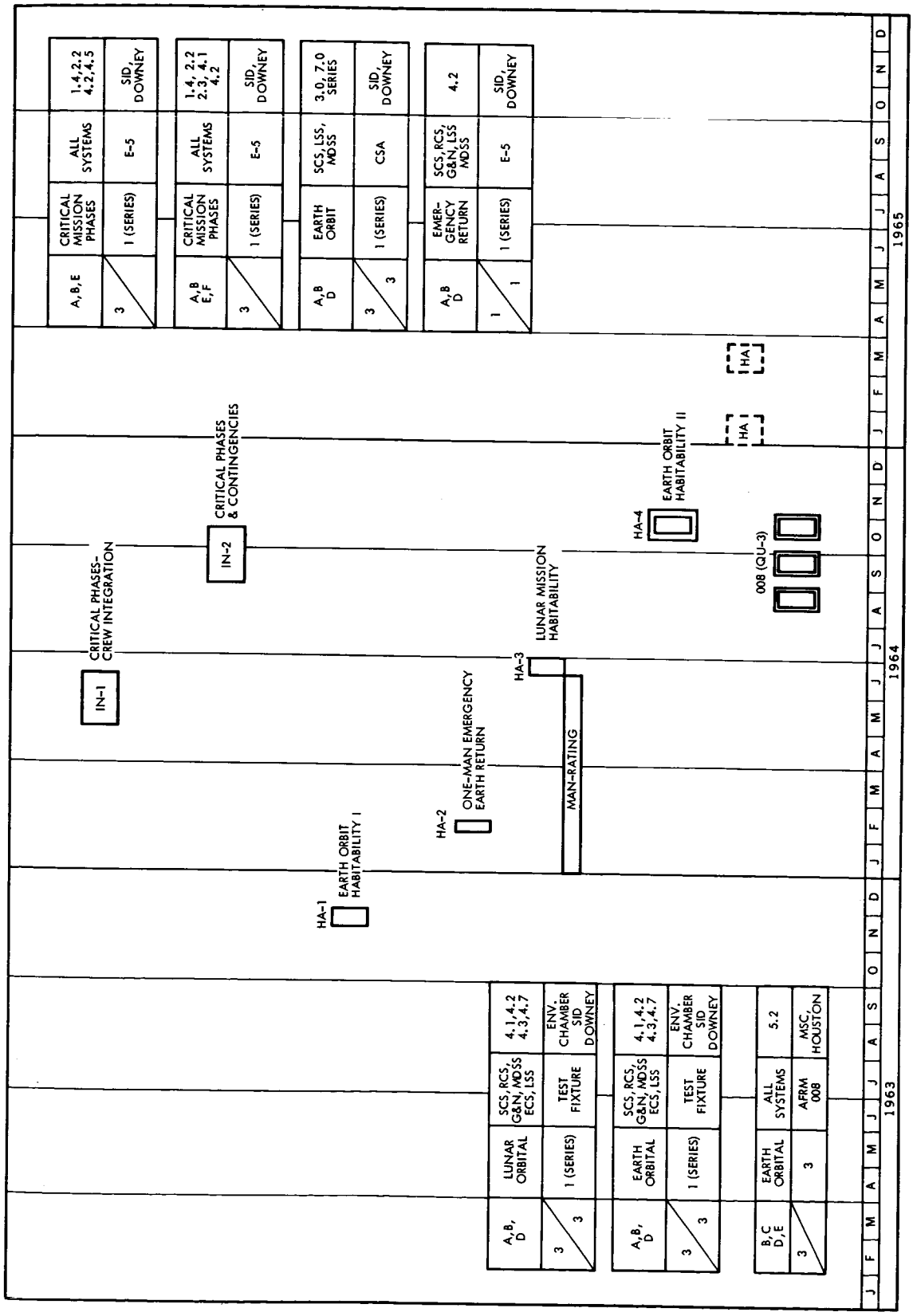

Figure 10-18. Crew Integration and Habitability Environment Test Schedule

[redacted]

6. Evaluate effectiveness of various auditory signals in alerting subject for duty.

7. Evaluate performance in nonpressurized, ventilated spacesuit.

8. Evaluate ability to handle emergency situations (i.e., malfunctions).

9. Evaluate capability of MDSS to relieve work load by monitoring system parameters and warning crewman of impending difficulty.

10.3.5.2.2 Test Requirements.

10.3.5.2.2.1 Task. During the first 68 hours of the mission, crewman will operate on duty periods varying in length from several minutes to several hours, interspersed with off-duty and sleep periods of from 1 to 2-1/2 hours. Crewman will remain on duty continuously for the last 12 hours of the mission, with 2 breaks for eating. Subject will be alerted for duty by various methods, including (1) flashing light, (2) voice, and (3) buzzer. Subject will wear a nonpressurized, ventilated pressure garment assembly at all times. The following tasks will be simulated in accordance with expected mission parameters: navigation sightings (1 per 3 to 4 hours during first 68 hours, numerous during last 12 hours); IMU alignment and V maneuvers (5 times for former, 4 for latter); S-band operations, EPS check, ECS check, receiving status report from MDSS (approximately every 2 hours); S/M RCS check (every 4 hours); SPS check (every 4 hours); EPS battery charge (every 6 hours); EPS fuel cell purge (every 8 hours); ECS scheduled maintenance (replacing lithium hydroxide canister every 12 hours); and C/M RCS check (every 24 hours). Attitude control problems prior to navigation sightings will be included. A vigilance task consisting of master caution and warning light monitoring will be included, requiring corrective action by the subject. Subject will fly an entry profile during the last hour of the mission. Physiological measurements will be made throughout the mission. An Apollo developmental food diet will be provided.

10.3.5.2.2.2 Variables.

1. Days

2. Methods of alerting subject for duty

3. Length of duty periods

4. Length of off-duty and sleep periods

[redacted]

5. C/M interior lighting (e.g., changes due to sunshafting)

10.3.5.2.2.3 Measurements.

1. Accuracy and efficiency of general performance and behavior over time

2. Effectiveness of each alerting method as measured by EEG and GSR readings during waking process

3. Subject's ability to detect, evaluate, and correct programmed malfunctions

4. Attitude control errors

5. G&N errors

6. Accuracy of earth entry performance

7. Errors in monitoring of master caution and warning lights

8. Physiological measurements include:

   a. EEG and GSR

   b. EKG

   c. Cabin temperature and relative humidity readings

   d. Suit: inlet and outlet temperatures and relative humidity; inlet flow rate

9. Checklist evaluation of suitability of personal equipment and procedures

10.3.5.2.2.4 Design.

   1. Schedule: 80-hour test, February, 1964. Two weeks of medical evaluation and task training will precede the test.

   2. Subjects: One pilot subject, three MDSS simulators (physiological monitors).

[redacted]

10.3.5.2.3 Equipment Requirements

1. Vehicle: E-5

2. Special Equipment: Crew systems test console

3. C/M Interior:

   a. Latest Apollo design display and controls

   b. Simulated guidance and navigation system (sextant and telescope with associate visual displays)

   c. Pressure garment assembly including provisions for vent air within test vehicle

   d. Sanborn tie-in for physiological measurements

   e. Two-way communications for MDSS simulation

   f. Operable entry indicator

   g. TV monitoring equipment

   h. Crew couches

   i. Life support provisions

   j. Personal hygiene and medical monitoring equipment

   k. Miscellaneous hardware

4. Computers: Analog computer to drive displays and controls and record measures

10.3.5.2.4 Facilities. S&ID facilities will be used.

10.3.5.3 Lunar Mission Environmental Habitability.

(Evaluation of crew performance and cabin habitability during simulated lunar orbit mission) Ha-3. (Co-conductor: Environmental control systems).

Ha-3 is basically designed to validate the environmental control system (ECS). As a result, the Apollo ECS group is prime in this test program. However, in order to assure that the system is exercised under realistic

[redacted]ENTIAL

[redacted]

mission loadings and to verify compatibility between the crew and the C/M environment, three subjects must perform tasks, work-rest cycles, and other crew duties under conditions which closely approximate those anticipated for a 14-day mission. As a result, Life Systems must support the test and assure that subsystems other than ECS are adequately simulated. Life Systems Test Plan is designed to validate task analysis, diet, crew equipment and systems, waste management, personal hygiene, communication procedures, and flight operations. Life Systems will be responsible for the necessary selection and training of subjects prior to the test. Life Systems personnel will also be responsible for the simulation of both C/M operations and MDSS operations during the test period. The final test plan drawn up by Life Systems will be reviewed by the latter group to accomplish its objectives for the overall test.

10.3.5.3.1 Objectives.

1. Evaluate crew metabolic levels on Apollo integrated tasks.
2. Verify ECS displays and controls.
3. Evaluate work-rest cycle.
4. Evaluate crew performance with and without pressure garment assemblies.
5. Dietary development
6. Evaluate food and waste management, personal hygiene, and first aid procedures.
7. Evaluate physiological and biochemical phenomena.
8. Evaluate ECS effects, outgassing, and controls.
9. Evaluate lighting.
10. Evaluate usage of crew equipment under environment of test and effect of environment on same.

10.3.5.3.2 Test Requirements.

10.3.5.3.2.1 Task. The crew will operate on a mission work-rest cycle, as determined by Task Design and Analysis. All subjects will be on duty during launch and entry phases. Subjects will wear ILC pressure garment assemblies during these phases. The following tasks will be simulated in accordance with expected mission parameters: navigation sightings,

[redacted]

IMU alignment and ΔP maneuvers, S-band operations, EPS check, ECS check, receiving status report from MDSS, S/M RCS check, SPS check, EPS battery charge, EPS fuel cell purge, ECS scheduled maintenance, and C/M RCS check. Attitude control problems prior to navigation sightings will be included. A vigilance task consisting of master caution and warning light monitoring will be included, requiring corrective action by the subject. Each subject will fly an entry profile during his last duty period. Physiological measurements will be made throughout. A dehydrated food diet will be provided.

10.3.5.3.2.2 Variables.

1. Days; duty periods
2. Pressure garment assembly versus constant wear garments
3. Cabin temperature, pressure, and gaseous content
4. Lighting variations
5. Exercise methods

10.3.5.3.2.3 Measurements.

1. Compatibility of displays and crew
2. Number of emergency indicator conditions missed and crew's ability to detect, evaluate, and correct programmed malfunctions.
3. Attitude control errors
4. G&N errors
5. Accuracy of earth entry performance
6. Effectiveness of voice received guidance instructions (MDSS)
7. Accuracy and efficiency of performance with and without pressure garment assembly
8. Physiological measures include:
   a. Impedance pneumograph readings
   b. EKG

c. Blood pressure

d. Oral temperature

e. Vital capacity

f. Water intake

g. Urine output

h. Body water

i. Microbiological control evaluation

j. Blood samples

k. Metabolic balance (total metabolic requirements)

l. Suit inlet and outlet temperature and relative humidity

m. Suit inlet flow rate

n. Helmet ΔP

o. Helmet pCO_2

p. Cabin temperature, relative humidity, gaseous content (especially pCO_2)

q. Oxygen requirements

r. Diet palatability and caloric adequacy

9. Checklist evaluation of suitability of personal equipment and procedures

10. Pilot opinion data

10.3.5.3.2.4 Design

1. Schedule: 10-day (224-hour)test; June 1964, (Preceding 5 months will be used for short duration man-rating tests.)

2. Subjects: Three pilot subjects, three MDSS (ground control) personnel.

10.3.5.3.3 Equipment Requirements.

1. Vehicle: ECS test capsule (equipped with instrument panel, C/M interior crew equipment, and breadboard ECS)

2. C/M interior:

   a. Latest Apollo display panel with simulated controls (including hand controller)

   b. Storage for CO_2 and odor removing container replacements

   c. Individual portable life support systems

   d. Biomedical measuring equipment

   e. Crew support equipment:

      (1) Personal hygiene supplies

      (2) Waste storage and management equipment

      (3) Food, food preparation, and food storage facilities

      (4) Medical supplies

      (5) Crew couches

      (6) Pressure garment assemblies (ILC)

      (7) Constant wear garments

      (8) Lapboards; logbooks

   f. Decontamination apparatus (cryo-oxide gas and ultra violet lamps)

3. Special Test Equipment:

   a. Crew systems test console

   b. Test capsule emergency repressurization

   c. Altitude chamber repressurization to 5.0 psia

d. Altitude chamber repressurization to 14.7 psia

e. Man air lock

f. TV cameras and audio system

g. Special urine storage system

h. Installation for biomedical monitoring

i. Capsule reinforcement to 52 psig

j. Toxic gas detection and warning system and gas chromatograph

k. Fecal, etc., sample transfer tube

4. Computers: Analog computer to drive controls and displays and record measures (200 channels)

10.3.5.3.4 Facilities. S&ID facilities will be used.

10.3.5.4 Earth Orbit Environment Habitability. Ha-4

(Duplicate Life Systems Test Ha-3, using the tasks designed for an earth-orbit mission and with minor modifications as indicated by Ha-3.) August 1964.

10.3.6 Transposition, Docking, and Rendezvous

10.3.6.1 Transposition and Docking

(Examination of procedures and equipment required to perform transposition and emergency lunar-orbital docking). TDR-1

10.3.6.1.1 Objectives.

1. Determine range of pilot ability for position and alignment accuracy at contact.

2. Determine the range of pilot ability in controlling translational rates.

3. Develop optimum pilot procedure for performing transposition and docking.

4. Determine the location and type of visual alignment aids, instruments, and lighting required.

5. Determine the effects of control modes, control contingencies, and spacecraft dynamics on pilot performance.

6. Verification of procedures

10.3.6.1.2 Test Requirements.

10.3.6.1.2.1 Task. Utilizing the SCS, visual aids, and instruments, the pilot will be required to perform the following maneuvers:

1. Transposition docking

2. Emergency docking

10.3.6.1.2.2 Variables.

1. Control systems

2. Thrust plane position

3. Alignment and position aids

4. Limit cycle rates

5. SCS quad failures

6. Pressure garment assembly operation

7. Exterior lighting

8. Control stick characteristics

9. Thruster utilization

10.3.6.1.2.3 Measurements.

1. Position at contact

2. Attitude alignment at contact

3. Propellant consumption

4. Rate of closure at contact

5. Rate of drift at contact

6. Time required for the maneuver

10.3.6.1.2.4 Design.

1. Schedule:

   Phase I - Feasibility - October, November, 1962.

   Docking A & B - Parameters - May, June, October through December, 1963.

   Docking C - Verification - May through September, 1964.

   Docking I - Verification - April through August, 1965.

2. Subjects: Three pilot subjects, one at a time.

10.3.6.1.3 Equipment Requirements.

1. C/M interior:

   a. Latest Apollo design instrument panel

   b. Latest Apollo design attitude and translational controller

   c. Pressure garment assembly (Class III) including provisions for vent air

   d. Command module communications system

2. Special equipment:

   a. Gimballed starfield

   b. LEM and S-IV-B models

   c. Position and alignment aids

   d. Closed circuit TV system

3. Computers: Analog and digital

10.3.6.1.4 Facilities. The NAA simulation laboratory facilities in Columbus, Ohio will be used.

10.3.6.1.5 Test Schedule. The transposition, docking, and rendezvous test schedules are shown in Figure 10-19.

10.3.6.2 Emergency Rendezvous

(Examination of procedures required to perform a successful one-man emergency rendezvous with the Apollo spacecraft providing the active propulsion) TDR 2 and 3

10.3.6.2.1 Objectives.

1. Determine pilot's ability to perceive relative motion between the two vehicles.

2. Determine pilot's ability to perceive and correct for relative motion.

3. Determine pilot's ability to make necessary initial ΔV and midcourse corrections required for an orbital transfer.

4. Determine optimum location and type of sighting aids required to initiate and complete an emergency rendezvous.

5. Determine what internal displays are necessary to aid in accomplishing this maneuver.

6. Explore possible communication procedure to assist in emergency rendezvous.

10.3.6.2.2 Test Requirements

10.3.6.2.2.1 Task. The pilot will be required to perform a complete emergency rendezvous utilizing the SPS, RCS, displays and controls, and visual aids as required.

10.3.6.2.2.2 Variables.

1. Locations and positioning of various sighting aids

2. Emergency rendezvous profiles

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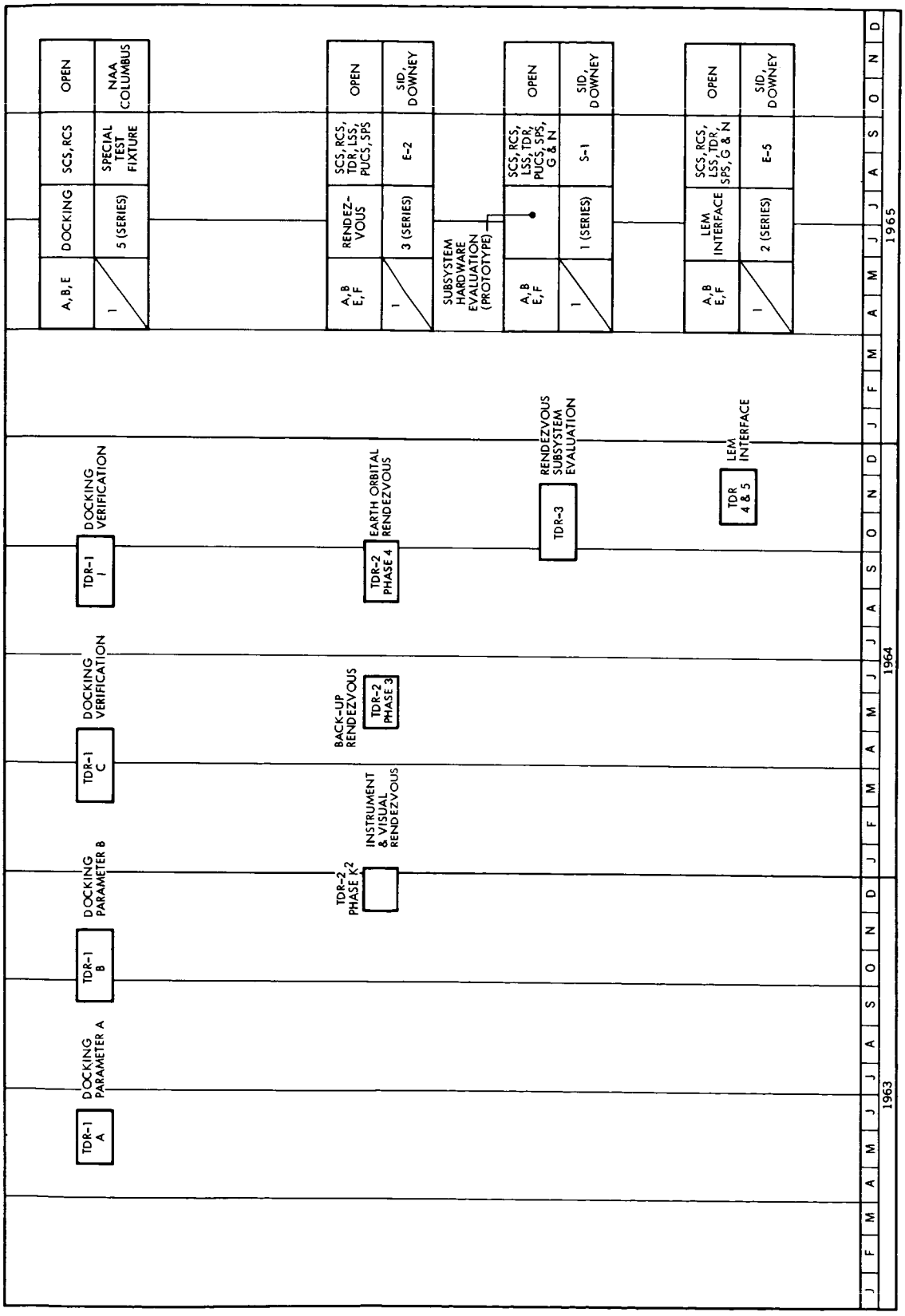

Figure 10-19. Transposition, Docking, and Rendezvous Test Schedule

3. Identification light on target vehicle

4. Lighting variations

5. Initial conditions

6. Various radar instrument displays

7. Various locations of SCT (scanning telescope) used to locate target and align radar antenna

8. LEM abort trajectories

10.3.6.2.2.3 Measurements.

1. Pilot's ability to perceive and correct for relative motion

2. Accuracy of orbit-to-orbit transfer

3. Attitude errors

4. Final position errors

5. RCS fuel expended for orbital transfer midcourse corrections

6. SPS fuel expended during ΔV required for orbital transfer

10.3.6.2.2.4 Design.

1. Schedule.

   a. Rendezvous Study No. 1 and 2. Instrument controlled versus visual rendezvous - 1 December 1963 through 4 January 1964

   b. Rendezvous Study No. 3. Backup rendezvous subsystems design requirements evaluation to run 1 May 1964 - 15 June 1964

   c. Rendezvous Study No. 4. Earth orbital rendezvous system design evaluation 26 August 1964 - 5 October 1964

   d. Rendezvous Study No. I. CSM rendezvous subsystem hardware compatibility evaluation to run September 1964 - 24 November 1964

10.3.6.2.3 Equipment Requirements.

1. Vehicle: E-2 - S-1

2. C/M Interior:

   a. Latest Apollo design rotational and translational controllers

   b. Pressure garment assembly including provisions for vent air

   c. Command module communications system

   d. Latest Apollo design instrument panel with the following systems active:

      (1) SCS including FDAI (CM)

      (2) RCS (CM)

      (3) ΔV - TVC

      (4) Radar electronics and displays

3. Special Equipment:

   a. Gimballed starfield

   b. External visual aids (gunsights, reticle, and simulated LEM with lights)

   c. Closed circuit TV

   d. Lunar surface

   e. Lighting equipment

   f. Special LEM models and/or lights

4. Computers: Analog and digital computer complex

10.3.6.2.4 Facilities. S&ID facilities will be used.

[redacted]

10.3.6.3 LEM-Apollo-CSM Interface Development

10.3.6.3.1 Definition. Studies of human performance involving the interrelationship between the Apollo CSM and the LEM. Particular emphasis is placed on the additional interface responsibilities and constraints as a result of CSM manning by a single crew-man during the LEM mission phase. TDR 4 and 5.

10.3.6.3.2 Objectives.

1. Evaluate crew task loading with respect to the interface between LEM and CSM during all flight phases.

2. Determine possible areas of task overloading and resultant system degradation.

3. Evaluate design and display configurations - specifically, operation and mission completion by one crew member.

4. Evaluate crew safety operations and ingress/egress techniques.

5. Evaluate mobility, manual dexterity, and reaction time in pressurized suits.

6. Determine extended necessity for MDSS communication as a function of combining CSM and LEM status reporting.

7. Study single crewman's CSM operations and resulting mission modification decisions in the event of a LEM failure.

10.3.6.3.3 Test Requirements.

10.3.6.3.3.1 Task.

1. Two combinations of test subjects will be used depending upon the mission phase or systems operations being studied. During boost, earth orbit, translunar injection, and transposition (and docking), a full crew's integrated task performance will be studied.

In the above noted combinations the test subjects will (in conjunction with MDSS):

a. Monitor LEM Status: And operational readiness during following mission phases.

[redacted]

(1) Earth orbit and translunar injection

(2) Transposition

(3) Transluner coast

(4) Lunar orbit injection

(5) Crew transfer and lunar descent

(6) Lunar orbit

(7) Lunar ascent, rendezvous, and docking

(8) Crew transfer and LEM jettison

b. Prepare for and perform:

(1) Interface as well as normal S/C duties

(2) System Verifications

(3) Recording and relaying LEM progress

(4) Navigational data processing (for LEM rendezvous)

(5) Ingress/egress tasks

(6) MDSS reporting

(7) Pressurization checks

(8) Continuity (power and system capability) checks

(9) Abort preparations

c. Assess and/or evaluate

(1) System degradation

(2) Damage and malfunction (isolation)

(3) Mission performance

(4) Requirements for abort

(5) Requirements for rescue

(6) Feasibility of mission continuation

(7) Feasibility of selective or limited mission completion

2. Through work measurement and task analysis, techniques including analysis of operations, MTM, and time-line analysis, duty cycles scheduling and task load balancing will be studied.

10.3.6.3.3.2 Variables.

1. Normal versus back-up modes

2. Task performance by a full crew complement versus a single crewman

3. Normal versus emergency modes

4. Control and display configurations with particular emphasis on single crewman operation

10.3.6.3.3.3 Measurements.

1. Pilot error rates - judgment and miscalculation.

2. Accuracy of performance.

3. Task time and balancing of tasks.

10.3.6.3.3.4 Design.

1. Schedule: To be determined.

10.3.6.3.4 Equipment Requirements.

1. Vehicle: E-5

2. Special Equipment:

a. LEM configuration access hatch

b. Space suits, back packs and O_2 bottles

c. Communications - MDSS, DSIF and Intercommunication with LEM interior

3. Special Assistance: MTM Personnel.

4. C/M Interior - Latest Apollo design, displays and controls.

5. Computers: SID 62-1303.

10.3.6.3.5 Facilities. S&ID facilities will be used.

10.3.7 Navigational Studies

10.3.7.1 Sextant Evaluation Study

(Determine accuracy of midcourse navigation fixes using the Apollo space sextant.) Na-1

10.3.7.1.1 Objectives.

1. Evaluate the ability of the navigator to perform navigation tasks on the sextant within error and time tolerances.

2. Provide data to point out relationships between error, sighting time, types of nearbody landmarks, residual drift rates both at start of run and when actual fix is made, and different sextant trunnion and shaft angles.

10.3.7.1.2 Test Requirements.

10.3.7.1.2.1 Tasks. Subject shall be presented a display through the eyepiece consisting of a star, a landmark, and a reticle. The star and the landmark will be located at some randomly determined area in the field of view and will be moving. The task will be to superimpose the star on the landmark using the two control sticks, and push the mark button at the instant they are superimposed.

When the full moon is used, the subjects shall superimpose the star on the limb of the moon at a tangent point defined by a line drawn parallel to the M-line and with the point of superimposition closest to the top of the field of view.

When crater detail of the moon is used the subject must center the star in a specified crater.

[redacted]

10.3.7.1.2.2 Variables.

1. Initial spacecraft random residual drift rates about three body axes.

   a. 1 arc min/sec

   b. 3 arc min/sec

   c. 5 arc min/sec

2. Sextant shaft angles.

   a. 0 degrees

   b. 60 degrees

   c. 120 degrees

   d. 180 degrees

3. Sextant trunnion angles.

   a. 30 degrees

   b. 45 degrees

4. Alignment techniques.

   a. Superimpose star on limb of moon.

   b. Center star in crater.

10.3.7.1.2.3 Measurements.

1. Alignment error:

   a. Separation of the star from landmark on the S_1 (R-line) axis of the sextant.

   b. Separation of the star from the landmark on the S_2 (M-line) axis of the sextant.

   c. Separation of the point of alignment from the R-line.

[redacted]

d. Separation of the point of alignment from the center M-line.

2. Time to complete an alignment.

3. Amount of fuel used for minimum impulse control for pitch, roll and yaw.

10.3.7.1.2.4 Design.

1. Schedule: 29 April - 1 June 1963. Training will be conducted the first two weeks.

2. Subjects: 10 male subjects from Apollo engineering personnel with uncorrected 20/20 vision, of which the best 5 will be chosen after training.

10.3.7.1.3 Equipment Requirements.

1. Computer - programmed to drive two X-Y plotters according to equations of motion.

2. Optics - composed of four aerial photography lenses, a beam-splitter, image of a simulated star and image of a simulated landmark, an adjustable eyepiece with an eyeguard.

3. Control panel - three operational controls and the eyepiece.

   a. The left control is a two-axis optics control stick.

   b. The right hand control is a three-axis minimum impulse control stick.

   c. The push button above the three axis stick is the "Mark" button which activates the camera.

4. Camera - 70 mm camera which will photograph the alignment.

5. Plotters - two X-Y plotters, one for star and one for landmark.

6. Reticle - a plastical rotatable reticle approximately six inches in diameter.

7. Pen recorder - 8 channel pen recorder will be used to record information about use of the minimum impulse control, optics control, and total alignment time.

10.3.7.1.4 Facilities. S&ID facilities will be used.

10.3.7.1.5 Test Schedules. The navigational studies test schedule is shown in Figure 10-20.

10.3.7.2 Scanning Telescope Study

(Determine accuracy of navigation tasks using the Apollo scanning telescope (SCT).) Na-2

10.3.7.2.1 Objectives.

1. Evaluate the ability of the navigator to use the scanning telescope on navigation tasks within established time.

2. Provide data to point out relationships between time of sighting, types of star fields, and different equations of motion (body rates).

3. Make preliminary estimates of crewman ability to recognize specific stars.

10.3.7.2.2 Test Requirements.

10.3.7.2.2.1 Tasks.

1. Subjects will perform the various procedures on the SCT as proposed by MIT and NAA.

2. Subjects will identify star fields and individual stars.

3. Subjects will perform lunar- and earth-orbit navigation fixes, verifying landmarks by comparison with landmark charts.

4. Subjects will perform midcourse navigation fixes.

5. Subjects will perform tasks required for IMU course alignment.

10.3.7.2.2.2 Variables.

1. Equations of motion simulating random residual drift rates around pitch, roll, and yaw axis; translation of the S/C through space, rotation of earth and moon, and lunar orbit around earth

2. Various distances from lunar and earth surface

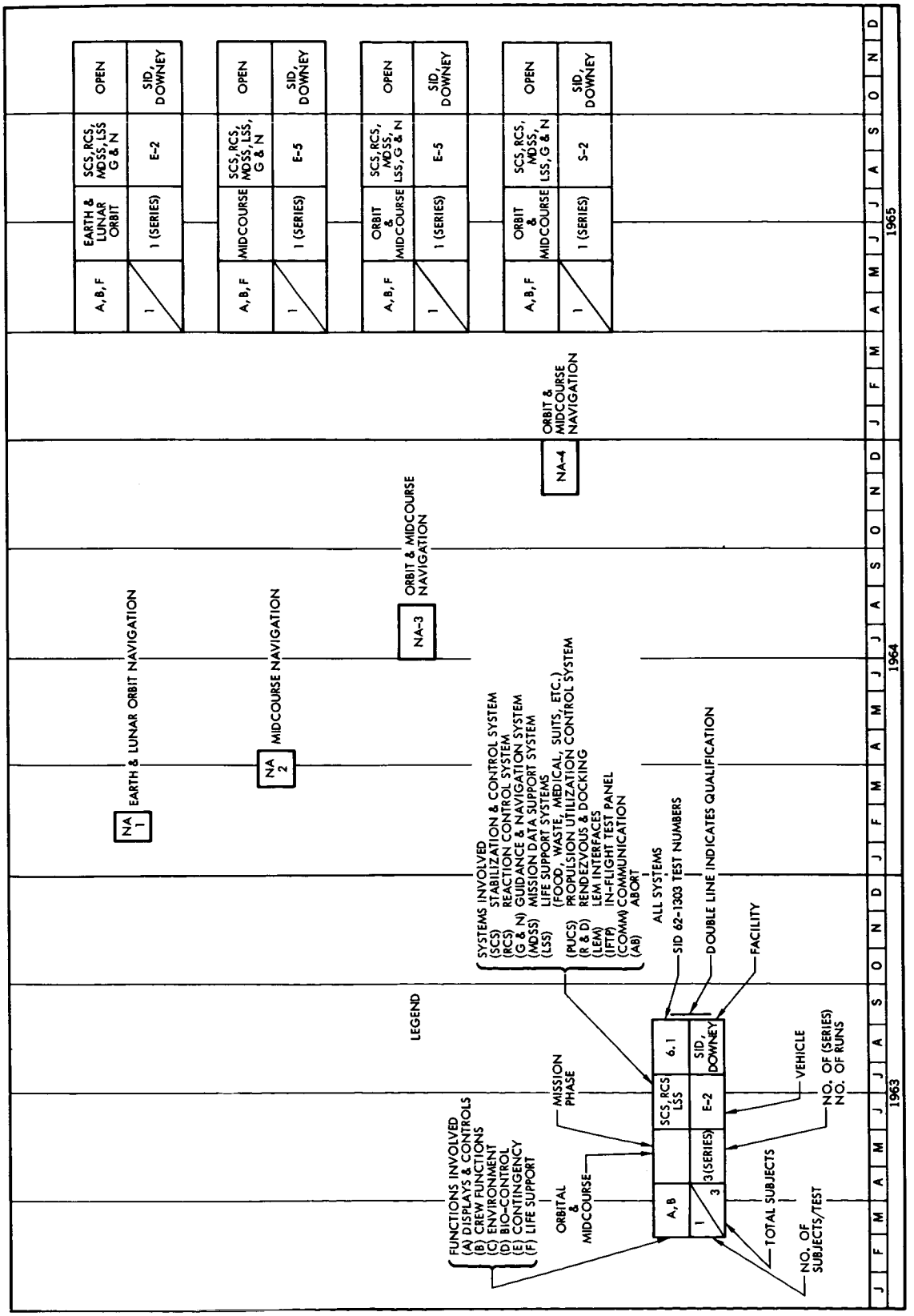

Figure 10-20. Navigational Studies Test Schedule

3. Performance with and without suit, and pressurized and unpressurized suit

4. Manual versus automatic modes

5. Illumination of landmarks and sky contrast

10.3.7.2.2.3 Measurements.

1. Amount of fuel used in navigation fix

2. Use of minimum impulse control

3. Use of optics control

4. Time to perform task

5. Identification errors

6. Target illumination and contrast at time of fix

7. Time of identification in relation to number of possible targets

8. Performance decrement with time

9. Performance decrement with increased task loading

10.3.7.2.2.4 Design.

1. Schedule: August, September and October, 1963. Training will be conducted the first 2 weeks of testing.

2. Subjects: Five subjects will be selected as in Na-1.

10.3.7.2.3 Equipment Requirements.

1. Computer - programmed to drive mechanism according to equations of motion of the S/C, earth, and moon

2. 3 X-Y plotters, one for earth landmarks, one for moon landmark, and one for target star

3. Optics - simulated scanning telescope with 60- and 20-degree fields of view, shielded eyepiece, and reticle

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4. Various star fields

5. Mark button

6. Optics control stick

7. Minimum impulse control stick

8. Data and check list chart

9. Simulated AGC keyboard with "enter" button, mode selector, neon light, angle readouts, and optics speed switch, IMU mode, map and data viewer, panel brightness, attitude disable, and condition lamp

10. TFE clock

11. Ten-channel pen recorder.

10.3.7.2.4 Facilities. S&ID facilities will be used.

10.3.7.3 Sextant and Scanning Telescope Combination Study

(Determine accuracy of navigation tasks using the Apollo SXT and SCT in combination.) Na-1

10.3.7.3.1 Objectives.

1. Evaluate performance of the human operator in navigation tasks, using both the SXT and SCT, within error and time tolerances.

2. Provide data to point out relationships between error, sighting time, sighting frequency, fatigue, types of landmark, types of star field, and different equations of motion.

10.3.7.3.2 Test Requirements.

10.3.7.3.2.1 Tasks. Subjects will perform four major Apollo navigation functions:

1. Earth-orbit navigation fixes

2. Moon-orbit navigation fixes

3. Midcourse navigation fixes

4. IMU course alignment

5. IMU fine alignment

Subjects will perform earth orbit navigation fixes for determination of orbital parameters for translunar injection and to fine align the IMU before injection.

Midcourse navigation fixes will be taken starting approximately 3/4 hour after translunar injection until 4-3/4 hours after injection at a rate of approximately 1 fix every 7 minutes. The IMU will be fine aligned for the first velocity correction. After the velocity correction, navigation fixes will be taken once every 30 minutes for the next 5 hours to establish S/C position and velocity.

Possible task overloading will be examined closely. The astronaut taking a navigation fix must operate the optics control stick with his right hand and the attitude impulse control with his left hand, while sighting through the SCT or SXT and comparing the field of view with the star or landmark chart on the viewer; he must also do simultaneously such things as adjust viewer brightness, select appropriate charts, operate AGC keyboard, select optics mode switch and optics speed switch, and select field of view, plus he has many other switches and controls to monitor and operate. Failure of any of the subsystems would increase an already complex task loading.

10.3.7.3.2.2 Variables. Same as Na-2, plus the following:

1. Failure of optics control stick

2. Failure of viewer and other subsystem failures

10.3.7.3.2.3 Measurements. Same as Na-2, plus the following:

1. Error in centering in SXT

2. Increase in error due to failure of various subsystems

10.3.7.3.2.4 Design.

1. Schedule: April through June 1964. Training will be conducted the first 2 weeks.

2. Subject: Five pilot subjects.

10.3.7.3.3 Equipment Requirements.

1. Computer and X-Y plotters - programmed to equations of motion of the S/C, earth, and moon.

2. Optics - simulated SCT and SXT similar to latest Apollo design

3. Variety of star fields

4. Complete G&N panel and controls

5. Complete AGC panel

6. Data and check list chart

7. Pen recorder - 10 channel

8. Camera

9. Special test vehicle, with interior as latest Apollo design with vibration profiles

10.3.7.3.4 Facilities. S&ID facilities will be used.

10.3.7.4 Prototype Navigation Equipment Study

(Determine accuracy of navigation tasks using prototype Apollo navigation equipment.) Na-4

10.3.7.4.1 Objectives.

1. Evaluate astronaut performance of Apollo navigation tasks using Apollo prototype navigation equipment within error and time tolerances.

2. Support Electronic Systems in determining prototype hardware interfaces.

10.3.7.4.2 Test Requirements.

10.3.7.4.2.1 Tasks. Subjects will perform all tasks, subtasks, and elements of all Apollo navigation functions as defined by latest MIT and NAA documents.

10.3.7.4.2.2 Variables. Same as Na-3

10.3.7.4.2.3 Measurements. Same as Na-3

10.3.7.4.2.4 Design.

1. Schedule: September, October, and November, 1964.

2. Subjects: Three subjects.

10.3.7.4.3 Equipment Requirements.

1. Prototype Apollo navigation equipment, panel, controls, charts, and data

2. Visual simulation with high fidelity of three different phases of the Apollo mission:

   a. Earth orbital

   b. Lunar orbital

   c. Midcourse trajectory

3. Necessary data recording equipment

4. Special test vehicle, with interior similar to latest Apollo design, capable of 5-psia, 100-percent O_2 and vibration profiles

5. Pressure Garment Assembly (Class IV) complete with environmental control subsystem - furnished by NASA

10.3.7.4.4 Facilities. S&ID facilities will be used.

[redacted]

11.0 GROUND SUPPORT EQUIPMENT

11.1 SCOPE

A GSE engineering test plan that results in a systematic approach to performance and specification characteristics of each unit of Apollo GSE is essential. Engineering and design verification tests will be performed on selected GSE to assure that the equipment meets the applicable requirements of design and performance. Applicable test data at certain levels of testing will be integrated and analyzed to assist in the over-all improvement of the deliverable equipment. The tests are divided into the following classifications:

Development tests
Qualification tests
Acceptance tests

11.1.1 Development Tests

The development tests will be determined by the design unit. Development tests will be conducted for the following purposes:

1. Evaluate materials and parts to assimilate general intelligence and application suitability data.
2. Acquire design or process improvement information.
3. Develop assurance that it will pass the qualification tests.
4. Determine design approach as compatible with requirements of this specification.
5. Locate significant failure modes.

11.1.2 Qualification Tests

Unless otherwise specified, the qualification tests will be performed on a unit produced with the same tooling and processes and under the same conditions as those intended for quantity production. All qualification tests will be conducted to demonstrate design integrity in accordance with the

requirements of the specification. Qualification tests will be performed at the bay or console level. Modules, panels, and commercial equipment, therefore, will not be tested as end items.

11.1.3 Acceptance Tests

The acceptance test will be performed on each deliverable end item. Any failures will be cause for rejection.

11.1.3.1 Classification Tests

Testing will be classified as follows:

Examination of Product
Functional Test
Performance Test

11.1.3.2 Examination of Product

The units will be examined to determine that the construction is in accordance with the drawings and requirements of the Design Control Specification, with respect to materials, workmanship, dimensions, and marking.

11.1.3.4 Functional Test

The units will be functionally tested per written functional test specification. Following satisfactory completion of the functional tests, each unit will be marked with an acceptance stamp by a representative of Quality Control.

11.1.3.5 Performance Test

The units will be tested with all associated items, including the spacecraft system. Only one test will be performed.

11.1.4 Rework

In the event any unit fails any part of the acceptance tests, the contractor may reject the entire lot of which the failed unit is representative and return to the subcontractor any unit of the lot which has been accepted. Upon satisfactory correction of the fault the unit as corrected may be resubmitted for acceptance tests. Documentation evidence of the rework will be submitted to the contractor.

[redacted]

11.1.5 Acceptance Test Record

A record of all acceptance tests will be maintained.

11.1.6 Failure Reporting, Analysis and Feedback System

Detailed malfunction data will be recorded as a part of the normal equipment testing operations. All failures will be analyzed and a corrective action implemented. Supplier forms to be used for reporting malfunction and corrective action will be in accordance with MC999-0025. The designation, "retest OK" is not acceptable; a complete analysis will be accomplished for all failures.

11.1.7 Adjustments and Repairs During Tests

There will be no adjustments, repairs, or maintenance other than those specified in the acceptance specification during testing. All items requiring repairs will be completely retested.

11.2 ECS SUBCONTRACTOR TEST PLAN (AIRESEARCH)

The environmental control system ground support equipment is to be built and tested by the AiResearch Manufacturing Division. This program encompasses the total effort required to support the study, design and development, qualification, manufacturing, assembly, and operational support of the GSE to be built by AiResearch. Applicable test data at all levels of testing (component, subsystem, and/or system) will be integrated and analyzed to assist in the over-all improvement of the delivered equipment.

11.2.1 Objectives

The objective of the AiResearch test program is to obtain evidence in the form of test data to confirm that the component and system design concepts are sound and that the equipment will operate properly when exposed to single or combined environmental operating conditions. This will assure the delivery of functionally qualified hardware.

11.2.2 Test Plan

The test plan for the ECS-GSE consists of three phases as follows:

Phase I	Development tests
Phase II	Qualification tests
Phase III	Integrated system verification tests

[redacted]

11.2.2.1 Phase I: Development Tests

Developmental tests are to be performed on the following two specific classes of GSE.

11.2.2.1.1 Direct Mission Essential Equipment. GSE in this category (Numbers refer to AiResearch part numbers) includes:

Water-glycol service unit 844700
Water-glycol trim control set 845800

The objective of the tests conducted on this equipment is to determine the functional capability of each GSE end item during a simulated countdown procedure. This will be accomplished by integrating the GSE with the ECS and conducting tests simulating precountdown, countdown, and postlaunch.

11.2.2.1.2 Indirect Mission Essential Equipment. GSE in this category (Numbers refer to AiResearch part numbers) includes:

Low-pressure gaseous test stand 844000
High-pressure gaseous test stand 844100
Liquid test stand 844200
Pressure distribution unit 845100
Suit loop stimuli generator 827510
Major subassembly bench maintenance test stand (AiResearch part number not yet assigned)

The objective of the tests conducted on this equipment will be to verify the instrumentation accuracy of each of the GSE test stands listed and its functional capability to check out the ECS components.

11.2.2.2 Phase II: Qualification Tests

As in Phase I tests, qualification tests will be run on direct and indirect mission essential equipment. In both categories of GSE, the test objectives will be to determine that the end items meet the performance requirements of their respective specifications and that the GSE shipping containers adequately protect the end items.

11.2.2.3 Phase III: Integrated System Verification Tests

Two complete ECS in-flight test and maintenance GSE systems will be tested to determine that the integrated system will meet the operational performance requirements under the combined environmental conditions of a simulated countdown and launch. In addition, data will be obtained on the operational life characteristics of the entire system.

[redacted]

11.2.3 Equipment

The new space and environmental systems laboratory will include the following:

1. Hard-vacuum chambers for component testing
2. Low-pressure chambers for subsystem and system testing
3. Vibration shake tables
4. High-low-temperature chambers
5. Miscellaneous bench-test equipment
6. Instrumentation including analog recording and digital readout and monitoring systems
7. High-vacuum and condenser blowdown system

In addition to the test equipment listed above, a new clean room with facilities for cleaning, testing, and packaging components, subsystems, and systems will be included in the new facility.

11.2.4 Facilities

The principal facilities of the AiResearch Manufacturing Company, which will be utilized for the Apollo Project, consist of two major manufacturing and laboratory installations and a remote desert test site. The main manufacturing facilities are located in Los Angeles and Torrance, California. The remote test facility is located at Boron, California. The design, development, and manufacture of the GSE for the ECS will be done at those facilities, each of which has an area exclusively devoted to the Apollo Program.

11.2.4.1 Manufacturing

The Los Angeles plant includes approximately 310,000 square feet of factory and warehouse area and approximately 74,000 square feet of engineering office area. It is not anticipated that additional building, or major modification of existing buildings, will be required for the manufacture of Apollo ECS-GSE.

[redacted]

11.2.4.2 Research and Development

The Los Angeles laboratory of AiResearch, including the Torrance and Boron facilities, occupies approximately 188,000 square feet of floor space. AiResearch funds are being used in the upgrading of these existing facilities to meet the requirements of the Apollo Program.

11.2.4.3 Testing

In addition to existing facilities, a new space and environmental systems laboratory with 22,000 square feet of floor space will be completed November 1963, at the Torrance plant. This laboratory, funded by AiResearch, will be designed specifically to test space and environmental control systems.

11.2.5 Test Schedule

The schedule for the environmental control system prototype GSE is presented in Figure 11-1.

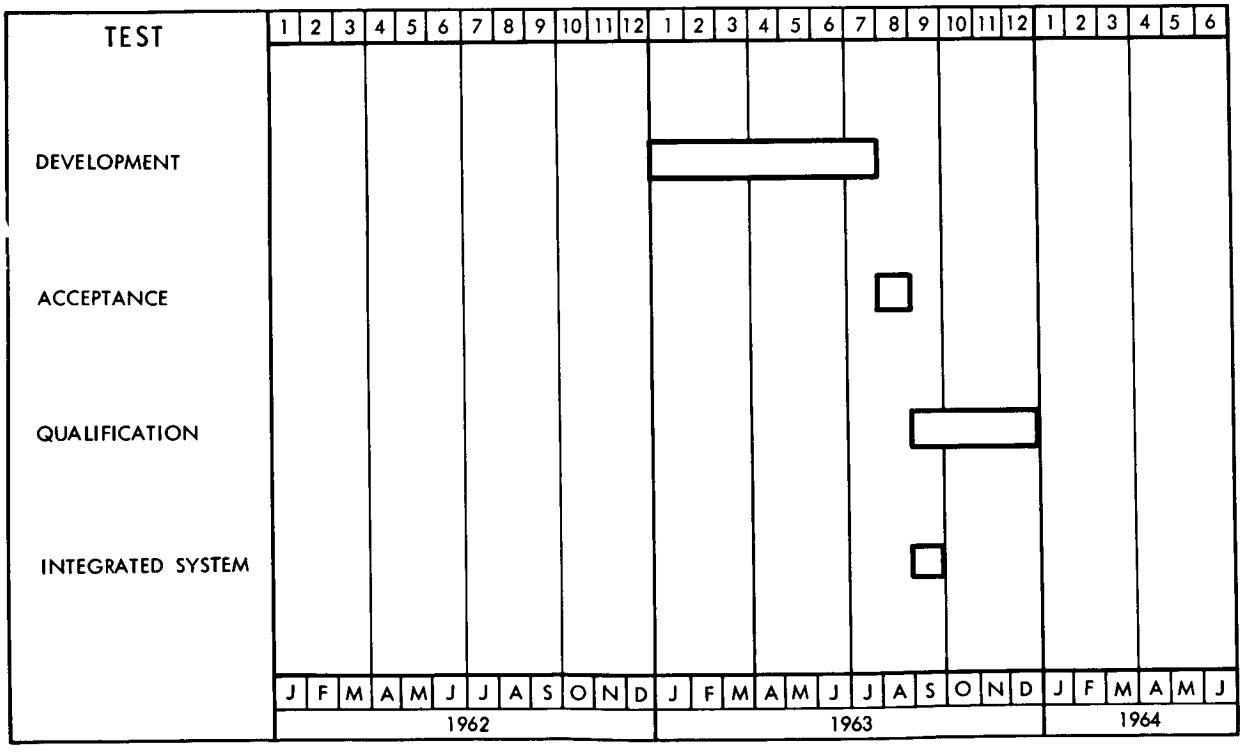

Figure 11-1. Environmental Control System Prototype GSE Schedule

[redacted]

11.3 SCS SUBCONTRACTOR TEST PLAN (MINNEAPOLIS-HONEYWELL)

The stabilization and control system GSE which consists of a bench maintenance test set and the auxiliary GSE will be manufactured and tested by the Minneapolis-Honeywell Regulator Company.

11.3.1 Objectives

Development, design evaluation, qualification, and acceptance tests will be performed to assure that the equipment meets all applicable requirements of design and performance. The tests will provide information in the form of test data which will demonstrate the compatibility of the GSE with the spacecraft, and also verify that the equipment will perform its function adequately and reliably.

11.3.2 Test Plan

The SCS-GSE test program will consist of the following tests.

Development tests
Design Evaluation tests
System GSE integration tests
Qualification tests
Acceptance tests

11.3.2.1 Development tests

11.3.2.1.1 Circuit Development Tests. During circuit analysis work, physical circuit hardware is built up and tested to prove out paper-work studies. As changes occur in flight hardware, the affected circuits for GSE will be incorporated and checked out for compatibility and integration into the final configuration.

11.3.2.1.2 Design Evaluation Tests. During this phase, an engineering evaluation testing of parts to select those suitable for use in the SCS-GSE will be conducted. This will include such studies as:

Determination of characteristics
Compartive tests to aid in selection
Evaluation of critical environments
Determination of performance stability and repeatability
Evaluation of changed an/or improved design

11.3.2.2. System-GSE Integration Tests

The bench-maintenance console will be checked out with the actual SCS system to demonstrate compatibility with the system.

11.3.2.3 Qualification Tests

This phase consists of a comprehensive series of performance tests conducted on panels or systems to demonstrate that the equipment meets all applicable requirements of design and performance.

11.3.3 Equipment

The following test equipment will be used in the test program.

Miscellaneous general-purpose instrumentation
GSE auxiliary equipment
Simulated SCS system loads
C-125 vibration simulator
Shock machine
Fungus chamber, Honeywell
Salt-spray chamber, Honeywell
Humidity chamber, Honeywell
High-low temperature chamber, Honeywell

11.3.4 Facilities

The tests will be performed at the Honeywell Aero Division facilities in Minneapolis and Roseville, Minnesota.

11.3.5 Test Schedule

The schedule for the stabilization and control system GSE is presented in Figure 11-2.

11.4 SUBCONTRACTOR TEST PLAN (PRATT & WHITNEY AIRCRAFT)

The fuel-cell power plant test stand will be constructed and tested by the Pratt & Whitney Aircraft Company. The test-stand test program encompasses the total effort required to support the study, design, development, qualification, and manufacturing of the fuel-cell test stands.

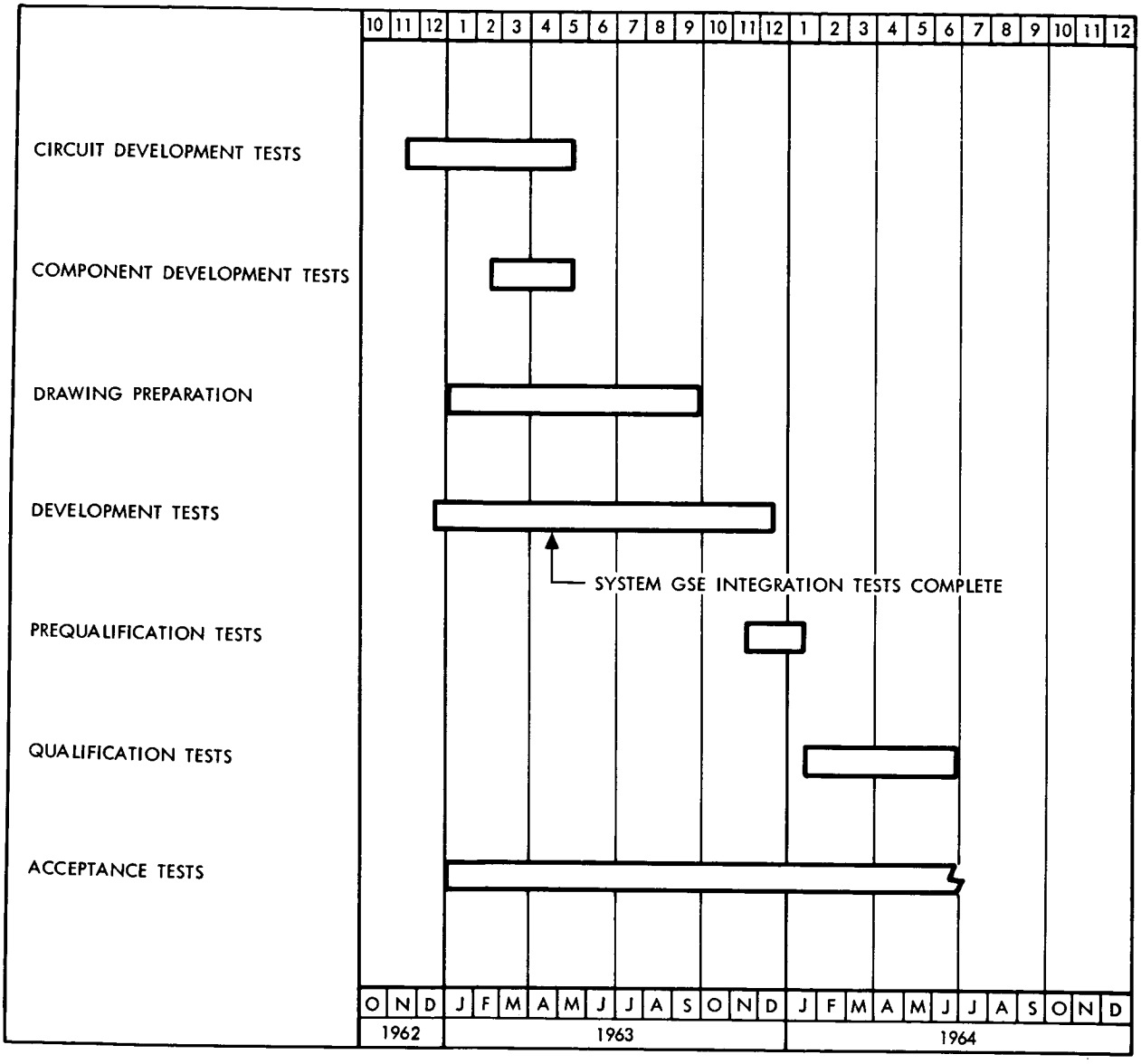

Figure 11-2. Stabilization Control System GSE Schedule

11.4.1 Objectives

The objective of the test program is to provide test data which will verify that the fuel-cell test stands function in accordance with the specifications and design requirements that have been established.

11.4.2 Test Plan

The inspection and testing of the test stands shall be divided into two phases.

11.4.2.1 Acceptance Tests

Each delivered unit shall be subjected to the following tests.

Examination of product (conformance to drawings and workmanship, etc.)
Dielectric
Operating (functional)

11.4.2.2 Qualification Tests

The extent of the qualification tests has not been determined at this time.

11.4.2.3 Operating Tests

The test stand shall be subjected to the following operating tests. During the operating tests, the test stand shall exhibit no malfunctioning, leaks, or other irregular operation.

11.4.2.3.1 Gas Supply System Test. The gas supply system shall be subjected to the following tests.

1. Leakage test. The gas supply system shall be pressurized with helium to 60 psia. Leakage shall be measured by pressure decay. The following maximum leakage rates shall apply.

Location	Power plant side of shut-off valves (cc/hr)	Supply side of shut-off valves (cc/hr)
Oxygen passages	5	100
Hydrogen passages	5	100
Nitrogen passages	5	500

The shut-off valves shall be closed.

2. Pressure regulator test. The gas supply system shall be connected to a nitrogen container and the following regulation demonstration shall be conducted.

[redacted]

Location	Minimum flow rate (lb/hr)	Maximum flow rate (lb/hr)
Oxygen passages	1.5	2.5
Hydrogen passages	0.75	11.0
Nitrogen passages	0.75	11.0

Location	Minimum pressure Power plant side (psia)	Maximum pressure Power plant side (psia)
Oxygen passages	250	1000
Hydrogen passages	100	300
Nitrogen passages	50	1500

The above shall be demonstrated with the nitrogen container at 2500 psia and at 1100 psia.

11.4.2.3.2 Data Readout System Test. The data readout system shall be operated to insure qualitatively the proper functioning of the equipment, including all operating controls.

1. Calibration stability tests. The following tests shall be conducted to establish compliance with accuracy requirements in the performance section of this specification.

   (a) The calibration of all measurement channels shall be established at 105, 115, and 125 volts.

   (b) The calibration of all measurement channels shall be established at periodic intervals over a period of 20 hours.

2. Linearity tests. The linearity of the readout system will be checked to establish compliance with the performance section of this specification.

11.4.2.3.3 Load Absorption System Tests. Tests shall be conducted to demonstrate the ability of the load absorption system to perform in accordance with the performance requirements of this specification. The load, when set at a predetermined level, shall not vary in excess of 5 percent of the set load.

11.4.2.3.4 Heat Rejection System Test. The unit shall demonstrate the ability to maintain a maximum temperature of the glycol mixture supply to the module of 175 degrees F at 80 pounds per hour glycol flow rate with clean, demineralized water supplied at a minimum of 70 degrees F and at a maximum pressure of 30 psia.

11.4.2.3.5 Power Output System Test. The power output system shall be operated to insure compliance with the performance requirements of this specification.

11.4.2.3.6 Dielectric Strength. The equipment shall be subjected to the dielectric withstanding voltage test, Method 301 of Standard MIL-STD-202. The test voltage shall be 1000 volts at commercial frequency and shall be applied between all circuits and the connector cases and the chassis. Immediately following this test, the equipment shall be tested in accordance with 11.4.2.3.7 and 11.4.2.3.8. Instrumentation circuits and components shall not be subjected to this test.

11.4.2.3.7 Insulation Resistance. The test stand shall be subjected to the insulation resistance test, Method 302 of Standard MIL-STD-202, test condition B. The potential shall be applied between each circuit and all other nonconnected circuits, the connector cases, and the chassis or frame, as applicable. The insulation resistance of each circuit shall be a minimum of 30 megohms.

11.4.2.3.8 Continuity. The continuity of each circuit of the test stand shall be verified to be in accordance with the test stand wiring diagrams and shall be checked by means of any commercial checking device or production test equipment employing such devices with an impressed voltage of 6.0 volts or less.

11.4.2.3.9 Leak Detector. The test stand shall be operated to insure proper functioning of the equipment. Test shall be conducted to establish conformance with fuel leakage and oxidizer leakage allowances.

11.4.3 Test Equipment

Equipment used to measure item parameters shall not introduce an error greater than 20 percent of the tolerance on the parameter. If a parameter tolerance is plus or minus 10 percent, the equipment error shall not be greater than plus or minus 2 percent.

The following categories of test equipment shall be used.

Electrical instruments
Pressure indicators
Temperature indicators
Flow indicators
PH indicators

11.4.4 Facilities

The acceptance tests on the fuel-cell test stands will be performed at the Pratt & Whitney Aircraft facility in Hartford, Connecticut. The test facility is equipped with hydrogen, oxygen, and nitrogen gas.

11.4.5 Schedule

The test schedule has not been determined at this time but will be included in the 31 March 1964 revision of this document.

11.5 COMMUNICATION AND DATA (C&D) SUBSYSTEM SUBCONTRACTOR TEST PLAN (COLLINS RADIO COMPANY)

11.5.1 Objectives

The objective of the test plan is to provide test data which will verify that the communications and data bench maintenance equipment (BME) will perform in accordance with established specifications and design requirements and to ascertain its compatibility with the applicable spacecraft equipment.

11.5.2 Test Plan

The C&D-BME test program will be divided into the following categories.

11.5.2.1 Engineering Development Tests

Engineering development tests will be performed on development models by design engineers to establish feasibility of design approach and to develop the design to operational maturity. Various phases of development tests are as follows:

Circuit development tests on nonstandard BME components
Component development tests on nonstandard BME components
Design evaluation tests on complete BME

11.5.2.2 Qualification Tests

Qualification tests may be conducted by Collins Radio Company to certify the C&D-GSE performance characteristics under specified environmental conditions. Testing shall not be required if objective evidence of specification compliance can be satisfied by any of the following documentation.

1. Data derived from recent qualification tests conducted on equipment similar in design and utilization

2. Data derived from development tests related to the specific component designed by CRC

3. Vendor certificate of compliance on standard commercial test equipment qualified by similar field application

11.5.2.2.1 Electromagnetic Interference Tests. These tests shall be performed on one deliverable end item in accordance with the requirements of the specification.

11.5.2.3 Acceptance Tests

Acceptance test will be made on each deliverable BME end item in order to determine compliance with the design and applicable specifications. The following are the categories of tests to be conducted during acceptance tests. Specific requirements will be delineated in a subsequent issue of this document.

11.5.2.3.1 Examination of Product. This test will determine that the end item conforms in all respects to the workmanship, configuration, size, etc., and is in accordance with all applicable drawings as specified.

11.5.2.3.2 Operating Tests. These tests will determine that the BME components (standard and nonstandard) provide signals and readout indication which are in accordance with specification requirements.

11.5.2.3.3 Spacecraft Equipment Package/BME Compatibility Tests. These tests will determine that the GSE is compatible with input/output requirements of applicable spacecraft packages and in no way will degrade their performance.

11.5.2.3.4 Spacecraft Subsystem/BME Compatibility. This test will determine that the GSE has the capability to check out spacecraft subsystem performance in open test (packages operated as they are normally interconnected in spacecraft installation).

11.5.3 Equipment Requirements

The following equipment will be available at CRC for the test support of C&D-GSE. Specific model numbers will be included in a subsequent issue of this document.

1. Temperature chamber
2. Altitude chamber
3. Humidity chamber
4. Vibration table
5. Shock impact table
6. RFI measuring equipment
7. Voltage and frequency standards
8. Miscellaneous standard test equipment

11.5.4 Facilities

The principal facility to be utilized during the BME program will be the Cedar Rapids Division of Collins Radio Company. Subtier efforts will be required during the design and development phase of nonstandard BME components. Subtiers of CRC are as follows:

Motorola, Inc., Chicago, Illinois (S-Band equipment)
ACF Industries, Inc., Paramus, New Jersey (C-Band equipment)

11.5.5 Test Schedules

Figure 11-3 describes tentative test schedules for the C&D subsystem GSE.

11.6 S&ID TEST PLAN (GSE HANDLING EQUIPMENT)

Design verification testing of GSE handling equipment will be performed by S&ID. The test program will include fit, function, and structural tests, designed to provide reliable hardware.

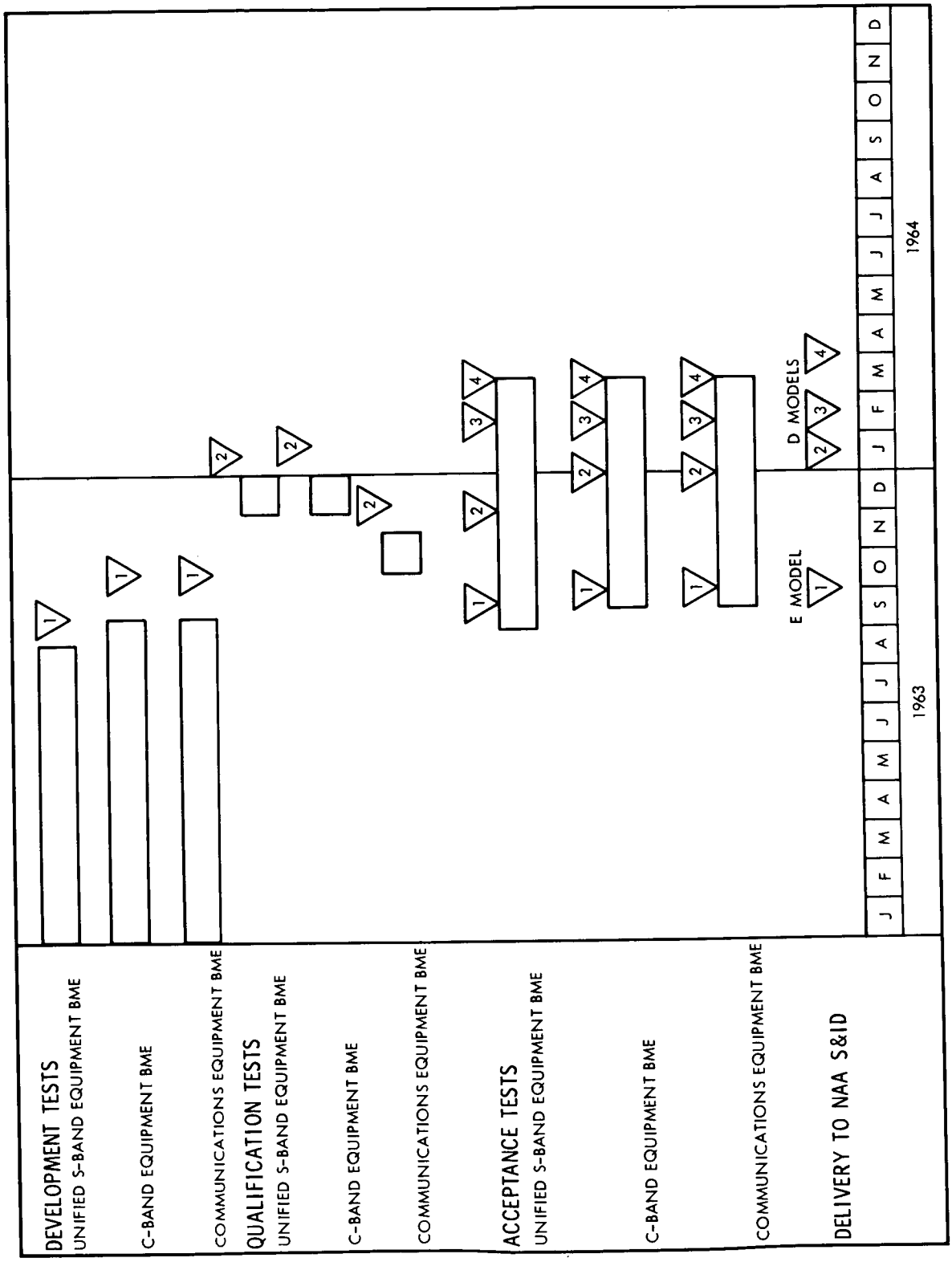

Figure 11-3. Communications and Data Subsystem GSE Test Schedule

[redacted]

The handling equipment is classified by categories as follows:

Positioning equipment
Transporting equipment
Work stands
Weight and balance fixtures

11.6.1 Objectives

The objectives of the test program are:

1. To demonstrate interface compatibility between spacecraft modules and GSE

2. To verify handling methods and procedures

3. To demonstrate structural integrity

4. To establish deflection and mobility characteristics

11.6.2 Test Plan

11.6.2.1 Positioning Equipment (Slings, Dollies, Support Bases)

1. Perform static structural tests as outlined in section 12.2.22

2. Perform fit and function tests using airframe and/or mock-up components

3. Perform qualification tests as defined in the detailed procurement specifications

11.6.2.2 Transportation Equipment (Trailers)

1. Perform static proof-loading tests as outlined in section 12.2.22

2. Perform fit and function tests using airframe and/or mock-up components

3. Perform qualification tests as defined in the detailed procurement specifications

[redacted]

[redacted]

11.6.2.3 Work Stands

1. Perform fit and function tests using airframe and/or mock-up components

2. Perform qualification tests as defined in the detailed procurement specifications

11.6.2.4 Weight and Balance Fixtures

1. Perform static structural tests as outlined in section 12.2.22

2. Perform fit and function tests using airframe and/or mock-up components

3. Qualification tests have not been defined at this time

11.6.3 Facilities

Tests will be performed at S&ID, Downey.

11.6.4 Schedule

The test schedule will be included in a subsequent revision of this test plan.

11.7 S&ID TEST PLAN (FLUID SYSTEMS GSE)

This plan covers the testing required to support the development and certification of fluid systems GSE.

11.7.1 Objectives

The GSE test plan objectives are:

1. To develop components and subsystems to the degree required to assure suitability and compatibility

2. To demonstrate compatibility and suitability of end-item systems with the system they are designated to support

3. To demonstrate that end-items and/or components are capable of satisfactorily performing under extreme environments

4. To monitor human engineering aspects during operation of equipment

5. To note suitability of safety provisions, and to verify that unsafe conditions have been minimized

6. To test the servicing provisions of the GSE by simulating servicing requirements

7. To establish the resistance of GSE to shock and vibration conditions

8. To observe equipment during other operational tests and ensure that undesirable characteristics such as smoke, fumes, noise, vibration, heat, etc., have been minimized to the greatest possible extent

11.7.2 Test Plan

11.7.2.1 Development Tests

During development tests, parameters of specific components and subsystems will be measured to provide engineering with data which will lead to the optimum design. These parameters will include pressure, temperature, flow, capacity, response times, and efficiency.

11.7.2.2 Design Evaluation and Acceptance Tests

Design evaluation and acceptance tests will be performed on the final design and completed end-items of the equipment to demonstrate satisfactory operation. These tests are concerned with ensuring proper output and input interface conditions in terms of pressure, temperature, flow, response time, capacity, efficiency, and safety.

11.7.2.2.1 Leak Tests. Leak tests will be conducted to assure there is no external leakage to the fluid system when the system is subjected to external working pressures. Hydraulic and pneumatic components will be subjected to proof-pressure tests to assure that no internal leakage detrimental to operation of the various units will exist.

11.7.2.2.2 Handling Provision Tests. Handling provisions will be tested to demonstrate servicing means are simple, safe, and compatible with associated servicing equipment.

11.7.2.2.3 Dielectric Strength Tests. Electrical components will be subjected to dielectric withstanding voltage tests, Method 301 of MIL-STD-202.

[redacted]

11.7.2.2.4 Insulation Resistance Tests. Electrical components will be subjected to insulation resistance tests, Method 302 of MIL-STD-202, test condition "B". The insulation resistance of each circuit shall be a minimum of 30 megohms.

11.7.2.2.5 Servicing Provisions. Servicing provisions will be tested to demonstrate servicing means are simple, safe, and compatible with associated servicing equipment.

11.7.2.3 Qualification Tests

11.7.2.3.1 Air Transportability Tests. Conformance with specification MIL-A-8421 will be verified.

11.7.2.3.2 Mobility Tests. Mobility of units will be demonstrated for compliance with specification MIL-M-8090 where applicable.

11.7.2.3.3 Environmental Tests. High-temperature and low-temperature tests will be conducted on the various units to determine the resistance of the equipment to the temperature extremes. Tests will be determined for each individual unit.

11.7.2.3.4 Humidity Tests. Humidity tests will be conducted on the various units to determine the resistance of equipment to the effects of exposures to a warm, highly humid atmosphere.

11.7.2.3.5 Salt Fog Tests. A salt fog test will be conducted on items of equipment that will be situated in unsheltered areas to determine the resistance of the equipment to the effects of a salt atmosphere.

11.7.2.3.6 Sand and Dust Tests. Sand and dust tests will be conducted on items of equipment situated in unsheltered areas to determine the resistance of the equipment to blowing sand and dust particles.

11.7.2.3.7 Vibration Tests. Vibration tests will be conducted on the various units to determine the effects of vibration on items with vibration isolators, and on others. Test procedure will be according to MIL-E-4970, as applicable.

11.7.2.3.8 Shock Tests. Shock tests will be conducted on the various units to determine the effects of shock. Test procedure will be per MIL-E-4970, as applicable.

11.7.2.3.9 Rain Tests. Rain tests will be conducted on units located in unsheltered areas, mainly to determine the efficiency of protective covers or cases designed to shield equipment from the elements.

[redacted]

11.7.2.4 Test Requirements

11.7.2.4.1 Fluid Transfer Units. Tests will be conducted on the fluid-transfer units to assure that objectives stipulated in paragraph 11.7.1 have been achieved.

The following parameters will be monitored.

1. Inlet pressures, temperatures, flow-rates, or quantity transferred aboard the spacecraft

2. Inlet and outlet temperatures, fluid pressures, and flow-rates from the transfer units

3. Time required to transfer required amount of fluids aboard spacecraft

The proper sequencing of system component functions will be verified. Leak-tight fluid and pneumatic systems also will be verified.

11.7.2.4.2 Checkout Units. A test will be conducted on checkout units to assure that all objectives stated in paragraph 11.7.1 have been achieved. Pressures and temperatures of pressurizing gases will be monitored to assure that excessive pressure drops do not exist in the fluid systems. Operation of various system components and leak-tight fluid and pneumatic systems will be verified. Proper operation of pressure regulating devices will be assured.

11.7.3 Equipment

Environmental chambers and associated equipment.

High-temperature chamber
Low-temperature chamber
Humidity chamber
Exposure chamber (salt fog tests)*
Fungus chamber*
Sand and dust Chamber*
Rain chamber*
Vibration machine
Leak detection devices
Flowmeters
Pressure gauges

*To be available for testing unsheltered end-items.

[redacted]

[redacted]

Temperature indicators
Timers
Meggers
Volt-ohm-meters
Ammeters
Watt meters
Recorders
Calibration equipment
Oscilloscopes
Audio frequency generators
Vacuum-tube volt meters
Signal generators

11.7.4 Facilities

Tests will be performed at S&ID, Downey.

11.7.5 Schedule

The test schedule will be included in a subsequent revision of this test plan.

11.8 S&ID TEST PLAN (CHECKOUT GSE)

11.8.1 Objectives

The objective of this plan is to support the development, design evaluation, and qualification and acceptance testing of the checkout GSE. The checkout GSE is divided into two general categories.

Manually operated checkout GSE
Automated checkout GSE

11.8.2 Test Plan

11.8.2.1 Development Tests

Electronic and mechanical functions will be analyzed to make a preliminary identification of the type of circuit and class of components to be used. On the basis of this analysis the nominal input-output values and component operational values will be defined. An engineering development laboratory test will then be conducted to establish and verify the feasibility of the circuits and the nominal input-output and component operational values. Any discrepancies between the empirical analysis and the laboratory test will be resolved prior to further design.

Further tests will then be conducted to compare and verify results of worst case and parameter variation analysis. These tests will consist of varying each of the circuit parameters through their worst case tolerances.

Measurements will be made on the input/output and component parameters, and comparison will be made between the measured values and the values predicted during the analysis phase. Any deviations from the predicted values will be investigated, and the reason for the deviations determined. The analysis will be corrected, and the circuit or function will be retested until the deviation falls within the expected value.

11.8.2.1.1 Design Evaluation Tests. Design evaluation tests will consist of applying the checkout system to the GSE verification simulator to demonstrate its ability to perform an adequate checkout. This test program will provide the necessary GSE for house spacecraft 1 and serve to further qualify the GSE.

The test article used in the design evaluation test will be an advanced R & D set of checkout equipment, incorporating the design features generated in the development tests. In addition, output recorders and miscellaneous laboratory test instruments will be used.

The test procedures will be established by Apollo Systems Test.

11.8.2.2 Qualification Tests

Qualification tests will be performed to demonstrate the ability of checkout system GSE to withstand the applicable environmental stresses without degradation of performance. Measurements of the systems generation of EMI as well as immunity to EMI will be made.

The test article will consist of a complete set of prototype checkout equipment. The test equipment will include:

Environmental test facility
S/C simulator and related equipment
EMI measurement facility

The general procedure will be dependent upon the design criteria applicable at the time of qualification.

11.8.2.3 Acceptance Tests

Acceptance tests will be performed on each deliverable end item of GSE. The objective of these tests will be to verify complete physical and functional compliance with all design documents.

The acceptance tests will be performed in two phases. The first phase consists of factory tests which verify that the equipment conforms to the drawings and all applicable specifications. The second phase will be a complete functional test which verifies that the equipment correctly performs all required functions.

[redacted]

The acceptance test article will consist of a deliverable set of checkout equipment.

The test equipment will include:

S/C or S/C simulator
Input/output equipment and data recorders
Functional test process specification
Test procedures

11.8.2.4 Automatic Checkout Systems Test Plan

11.8.2.4.1 Objectives

1. To assure qualification of individual concepts and to make a preliminary evaluation of the data handling system

2. To evaluate over-all system performance and to determine the statistical reliability of the system

3. To solve the timing problems which will be involved and verify qualification of solutions

4. To develop satisfactory data formats and their effect on programming and logic complexity

5. To develop and verify self-check and auto-check methods and to eliminate verification simulator redundancy

6. To verify the functional integrity of checkout systems GSE and PACE and their compatibility with the spacecraft systems

7. To determine the adequacy of PACE in detection and isolation of critical systems failure down to the lowest replaceable module

11.8.2.4.2 Development Tests. The first phase will consist of breadboard tests for development of PACE circuits and subsystems. The basic purpose is to study the feasibility of the present checkout concept and to give a preliminary evaluation of the proposed data handling system. The breadboards will have the following detailed objectives.

1. Evaluate the performance of local subcommutators and optimize their design.

2. Evaluate analog to digital conversion techniques.

3. Evaluate performance of the various components of the digital command system.

4. Study compatibility of the various components with each other.

The equipment to be tested will include the major components of the checkout system, including special circuits which will be designed as a part of this development. The list of equipment will include:

C14-210	Carry-On PCM subsystem
C14-211 Through C14-215	Substitute units
C14-230	Data interleaver system
C14-240	Servicing equipment PACE S/C adapter substitute unit

The general procedure will consist of running performance tests on the system components. These components are then connected to their interfaces and operated as a system or subsystem.

The second phase will be the first complete checkout system test and will have the following detailed objectives.

1. Integrate the components of a complete checkout system and evaluate over-all system performance.

2. Study GSE system timing problems which may be encountered in component subsystem assembly.

3. Study data formats and their effect on programming and logic complexity.

4. Develop self-check and auto-check methods and eliminate verification simulator redundancy.

5. Verify PACE system programming, and compatability with the control room and other GSE systems.

The test article will consist of a complete R & D checkout system, functionally as near like the prototype system as possible at this stage of development. The test equipment will consist of control consoles, pattern recognizer, command word generator, output display unit, PCM signal simulator, and general purpose laboratory test equipment. The general test procedure will be to assemble subsystems and to verify compatibility of each. Comprehensive tests are then to be performed on the complete system as required to achieve the stated objectives.

[redacted]

11.8.3 Test Equipment

The following list of test equipment will be required to support the testing of the carry-on GSE and for verifying and maintaining the individual subsystems.

Description	Quantity
Square wave generator, 105, Tektronix	1
Pulse generator, 212A or equivalent, Hewlett-Packard	2
Regulated power supply - variable 0-30 VDC - 20 amps	1
Digital voltmeter, V35B or equivalent, nonlinear systems	2
Multimeter, 630 or equivalent, Triplett	5
VTVM, 412A or equivalent, Hewlett-Packard	1
Differential voltmeter, 803 or equivalent, John Fluke	2
Frequency counter, 8360 or equivalent, Beckman	1
Oscilloscope, 545, Tektronix	4
Scope-mobile cart, 500/52A, Tektronix	3
10X Probe, 6022, Tektronix	4
Plug-in, C/A, Tektronix	4
Plug-in, D, Tektronix	2
Plug-in, L, Tektronix	1
Impedance bridge, 250 or equivalent, Electro Sensitive Instruments	1
Resistance Decade Box, 14322 or equivalent, General Radio	1

[redacted]FIDENTIAL

[redacted]

Description	Quantity
Dual Beam, 565 or equivalent, Tektronix	1
Plug-in, 3A74 or equivalent, Tektronix	2
Oscilloscope camera, C-12, Tektronix	1

The following list of loose equipment will be required in addition to the above for the support of the PACE test program.

Description	Quantity
Vertical rack	10
Video pair cable (3 pair) 124 ohms, General cable 1695VL	2500 feet
Coaxial cable RG191V	1000 feet
Video patch cable	1
Patch cables	1 set

The development and testing of the checkout system GSE will be conducted at the Downey facility of S&ID and at the NASA facility at AMR. The facility will contain the following equipment:

Digital computer	CDC Model 160-A
Input/output typewriter	CDC Model 161
Magnetic tape units	CDC Model 163-3
Line printer	CDC Model 166-2
Auxiliary arithmetic unit	CDC Model 168
Auxiliary memory unit	CDC Model 169-1
Card read/punch unit	CDC Model 1609
Incremental plotter	CDC Model 165
PCM ground station and decommutator	
Computer input/output buffer	
Monitor and control console	
Decommutator system and MTO	
Flex-O-Writer	
Key punch	
Card to tape unit	

[redacted]

C/M simulator
S/M simulator
Carry-on interface simulator
PCM simulator
Command monitor and display
Response system output display
CRT display

11.8.4 Test Schedules

The test program schedule for the PACE Breadboard No. 1 is shown in Figure 11-4. Breadboard No. 2 test schedule is to be established.

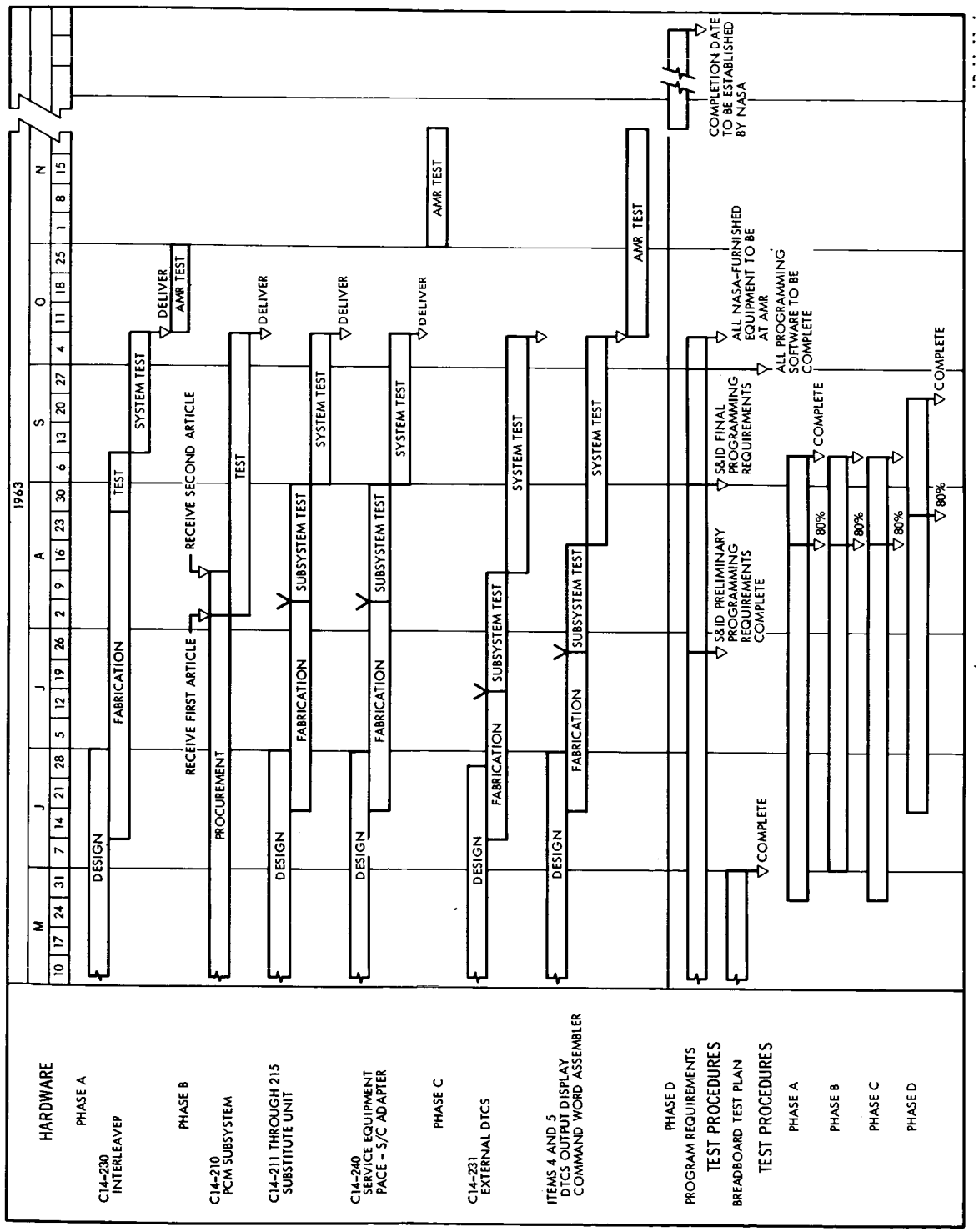

Figure 11-4. Breadboard No. 1 Test Program Schedule

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12.0 STRUCTURAL TESTS*

12.1 SCOPE

The structural test program encompasses the development and design verification testing accomplished by S&ID to verify conformance of the Apollo spacecraft components and structure with the critical mission environments and loads. The program includes testing of components and complete structures of command module, service module, spacecraft adapter, launch escape tower, and combined structures. Subassembly evaluation testing of structural members, including joints, truss sections, welds, tankage, windows, heat shield, crew couches, and motor supports, will be conducted by applying limit loads for major critical design conditions and then by applying ultimate design loads. The test specimen will be loaded to failure for a selected condition for each test to determine the maximum load capability.

The tests outlined herein are supplemented by tests described in Section 13 (Mechanical Devices), Section 14 (Materials, Processes, and Producibility), and Section 16 (Thermal Protection System) and by tests conducted on boilerplates and airframes.

12.2 S&ID TEST PLAN

12.2.1 Command Module Tests

12.2.1.1 Static Structural Tests

12.2.1.1.1 Objectives. Design evaluation tests will be performed at room temperature on the full-scale command module to verify the structural integrity and structural analysis under critical design conditions. The stress distribution and deflection characteristics in selected locations, strength stability, and mode of failure will be determined.

12.2.1.1.2 Test Plan. The command module will be mounted in a test fixture that provides for application of the various simulated loads and related reactions. A refurbished tower or jig will be employed for applying loads at the command module tower attachment points. The applicable loads and pressures for critical abort, main parachute deployment, 20-g entry, and crew compartment burst conditions will be simulated.

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For each test condition, except burst, the test loads will be applied in convenient increments. The resultant load will be reacted through linkages to simulate actual inertia loading. Static loads will be applied by hydraulic struts. Pressures will be applied to the test article, externally or internally, as required. Strains and deflections will be recorded in critical areas and monitored during the test to detect possible premature failure.

12.2.1.1.3 Equipment. The equipment required will consist of load and pressure transducers, strain gauges, deflection devices, and related recording equipment; pneumatic and fluid pressure regulators and hydraulic load struts; load and pressure application and reaction jigwork; and GSE for transport and hoisting of the command module.

12.2.1.1.4 Facilities. The S&ID laboratory at Downey, California, will be used for the test program.

12.2.1.1.5 Test Schedule. Testing will start 1 January 1965 and be completed October 1965.

12.2.1.2 Landing Impact and Stability (Land and Water) Tests

12.2.1.2.1 Objectives. The purpose of the tests is to obtain data on the landing impact vehicle dynamics and the subsequent response of the equipment, structure, crew seat system, and crew under a variety of landing conditions, both normal and emergency. These data will assist in the development of a satisfactory impact attenuation system for the Apollo command module crew couches.

12.2.1.2.2 Test Plan. The general procedure for testing will be to make a series of drops with different impact conditions. Velocities will range from 22 to 33 fps, vertically, and from 0 to 51 fps, horizontally. The attitude will vary from 0 to 360 degrees about the X-axis, from -10 to -50 degrees about the Y-axis, and from 0 to ±20 degrees about the Z-axis Surface types will vary from soft to hard earth, as well as water, with slopes from 0 to ±15 degrees.

Boilerplates 1, 2, and 28 will be used for this effort to provide for the development of the crew impact attenuation subsystem. Airframes 005, 007, and B-28 (described under command module static structural tests) will be impacted on land and on water for design verification of the spacecraft.

12.2.1.2.3 Equipment. Suitable display and quick-loop analysis equipment and magnetic tape recorders will be required to monitor and record, via land lines, the following information:

1. Impact acceleration and loads (triaxial and biaxial accelerometers on the command module structure and crew couches)

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2. Dummy response (See life system tests, Section 10)

3. The impact sequence will be recorded on high-speed motion pictures with grid background to determine impact and slideout attitudes and velocities.

12.2.1.2.4 Facility. A facility to meet the specific requirements of these tests has been built at S&ID and was completed in March 1963.

12.2.1.2.5 Test Schedule. Test completion is dependent upon confirmation of the optimum boilerplate landing configuration. AFRM 005 will be used to confirm the final landing concept.

12.2.1.3 Model Test-Landing Impact and Stability

12.2.1.3.1 Objectives. This model test will obtain more complete parametric data than is currently possible with the boilerplate program. Landing-impact acceleration and stability envelopes, in terms of landing velocities, ground slope, type of terrain, sea state, command module attitude, etc., will be determined.

12.2.1.3.2 Test Plan. Two models will be used in the program. Both will be one-quarter scale, but one will simulate a prototype C/M with the heat shield directly attached, while the other will have a shock attenuation subsystem and a heat shield. Model stiffness will be determined for both. A series of drops will be made with different impact conditions. Velocities will range from 23 to 33 fps, vertically, and from 0 to 51 fps, horizontally. The attitude will vary from 0 to 360 degrees about the X-axis, from 0 to -10 degrees about the Y-axis, and from 0 to ±5 degrees about the Z-axis. Drops will be made on various surface types and slope angles and into water. This program is being conducted under NASA primary cognizance. S&ID has provided technical guidance and has monitored the test operations.

12.2.1.3.3 Test Requirements. It is required that complete impact acceleration and stability envelopes be determined.

12.2.1.3.4 Equipment. Impact accelerometers, recording oscillographs, and associated equipment are required.

12.2.1.3.5 Facilities. Langley Research Center facilities are being used.

12.2.1.3.6 Test Schedule. Land impact tests were completed approximately 1 January 1963. Water landing tests scheduled by Langley Research Center began 15 January. S&ID is monitoring these water landing tests. The final test report is the responsibility of Langley Research Center.

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12.2.1.4 Vibration Test of Typical Structural Panels

12.2.1.4.1 Objectives. This program will determine natural response modes and vibration fragility levels of sample structural panels, evaluate vibration resistance of panel attachment methods and ablative material bonding agents, and measure damping. Effect of elevated temperature on C/M vibration response and fragility will be determined.

12.2.1.4.2 Test Plan. A series of exploratory tests will be conducted, using mechanical impedance techniques, to ensure that realistic boundary conditions are applied during the modal and vibration fragility tests. The C/M structural section, in particular, will require extensive mechanical impedance analysis prior to application of environmental vibration. Final tests will include the application of simulated mission environmental vibration.

12.2.1.4.3 Test Requirements. Panel vibration modes and the fragility levels of ablative bonding and C/M structural attachment methods must be determined.

12.2.1.4.4 Equipment. Electrodynamic shakers, associated monitoring and measurement systems, tape recorders, test jigs, and data reduction equipment will be required.

12.2.1.4.5 Facilities. S&ID facilities will be used.

12.2.1.4.6 Test Schedule. Test completion is dependent upon final design freeze of C/M ablative and hull structural detail and S/M and adapter panel detail.

12.2.1.5 Sonic Tests of Typical Structural Panels

12.2.1.5.1 Objectives.

1. To determine acoustic transmissibility and susceptibility to sonic fatigue of the sample (representative of command module, service module, and adapter structure) when exposed to sonic excitation equivalent to that expected from booster engines, aerodynamic noise (launch and atmospheric reentry), and abort system engines

2. To evaluate the effect of elevated temperatures (reentry heat loads) on vibration response characteristics of the ablative heat shield panel

12.2.1.5.2 Test Plan. Vibration response, natural modes, and strain of panels exposed to random broad-band, random narrow-band, and discrete frequency sonic excitation will be determined. Acoustic transmissibility and panel dynamic damping will also be determined.

12.2.1.5.3 Test Requirements. Acoustic transmissibility, vibration modes, fragility levels, and damping data are required.

12.2.1.5.4 Equipment. Acoustic, vibration, and strain measurement systems, magnetic tape recorders, and analog data reduction equipment will be needed to compute octave and one-third octave band spectrums, power spectral densities (pressure, acceleration, and strain), and correlation functions.

12.2.1.5.5 Facilities. S&ID facilities will be used.

12.2.1.5.6 Test Schedule. Test completion is dependent upon final design freeze of C/M ablative and hull structural design and S/M and adapter panel detail. The completion of S&ID acoustic facilities may also affect test completion.

12.2.1.6 Command Module Base-Structural Components

12.2.1.6.1 Objectives. It will be necessary to perform static development tests on the base section, under the combined design conditions of entry pressures and inertia loads at room and moderately elevated temperatures, in verification of the structural integrity and design feasibility of the base pressure walls, floor, and other attached structures to simulate the following:

1. Launch-inertia loads at room temperature on the base section for defining load-deflection characteristics

2. Pressurization at the interior of the base section at room temperature and also with the heat shield substructure at moderately elevated temperatures to correspond to the design interface temperature and heat input

3. Design entry and inertia loads on the base section at room temperature and also with the heat shield substructure at moderately elevated temperatures to correspond to the design interface temperature and heat input

4. Abort loads at room temperature on base heat shield substructure for defining load-deflection characteristics

These tests will provide stress, load path, deflection, and thermal data for the full-scale command module tests on Airframe 005, No. 2 static-test article.

12.2.1.6.2 Test Plan. Loads, in most cases, will be applied to the back face of the heat shield substructure through the base floor and reacted at the aft wall peripheral attachments. The same reaction methods will be employed for the pressure tests. Tests will be conducted on the base section at room and moderately elevated temperatures while the section and fitting are under static simulated design earth-impact loads.

For the pressure test, the command module base component will be mounted in a test fixture for support and close-out of the structure that is to contain pressure. A suitable, noncorrosive fluid will be used to fill the enclosure and to act as the pressurization medium. Strain gauges and deflection indicators will be located to give maximum design information. The pressure and loads, if applicable, will be increased in increments to design values and then to ultimate values, with measurements recorded at each increment. Strain and deflections will be monitored during the test to detect possible premature failure.

For the launch-condition test, the command module base component will be mounted in a test fixture for support and load application. This condition test will be conducted at ambient temperature. Load cells and hydraulic load struts will be used to react and to apply required loads through conventional whiffletree arrangements. Strain gauges and deflection indicators will be located at critical points. Loads will be increased in increments to design values and then to ultimate values with measurements recorded at each increment. Instrumentation will be monitored during the test to detect possible premature failures.

For the abort condition, the test will be performed similarly to the foregoing, but the loading spectrum will be as required for simulation.

For the entry condition, the test setup will be similar to that already described, but a radiant heat lamp oven and its attendant supporting structure will be added. Thermocouples for control and monitoring will be imbedded and attached throughout the structure. A sufficiently realistic load and thermal environment will be achieved, if possible, by static load and heat applications; otherwise, programmed load and heat will also be used.

This test program will use the base section of the command module, consisting of the following parts: complete pressure vessel base and floor structure, adjacent aft-wall structure for load attachment, and base heat shield substructure without heat shield.

12.2.1.6.3 Equipment. Load and pressure transducers, strain guages, deflection devices, and related recording equipment will be needed, as well as hydraulic load struts and load and pressure application and reaction jigwork. Required also will be fluid pressure sequence regulators and cyclic timers, thermocouples, and recording equipment. Radiant heat facility and/or hot air heating will also be required as needed for elevated temperatures and the attendant heat controllers. Gas regulators, sequence valves, manifolds, and GN_2 supply will also be supplied.

12.2.1.6.4 Facilities. S&ID facilities will be used.

12.2.1.6.5 Test Schedule. Tests are to be completed by March 1964.

12.2.1.7 Command Module Sidewall Structural Components

12.2.1.7.1 Objectives. The objectives will be to perform static development tests on a semi-circular sector of the command module sidewall and component parts, including heat shield substructure, under the conditions of load and pressure for launch, abort, flight, lunar orbit, entry, and earth landing.

12.2.1.7.2 Test Plan. The command module sidewall component will be mounted in a test fixture that will provide for tension and compression axial loading, as well as crushing and burst pressurization loading. Strain gauges and deflection indicators will be located to provide design and development information. Various combinations of pressure and loads will be applied to simulate the various critical design conditions. Complete instrumentation records will be kept for each condition or combination. The instrumentation will be monitored during each test to detect premature failures. The sidewall section of the prototype command module will consist of the following components: crew windows, crew access hatch, heat shield substructure, and other applicable parts and supporting structure on, or integral with, the pressure-vessel sidewall. A semicircular sector of the sidewall with longerons attached and extending from the forward bulkhead to part of the aft wall (and including it) is required.

12.2.1.7.3 Equipment. The following items will be required: load and pressure transducers, strain gauges, deflection devices, and related recording equipment; hydraulic load struts; load and pressure application and reaction jigwork; load and pressure sequence valves and cyclic timers; gas regulators, sequence valves, and manifolds.

12.2.1.7.4 Facilities. S&ID facilities will be used.

12.2.1.7.5 Test Schedule. Tests are to be completed by March 1964.

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12.2.1.8 Command Module Apex Structural Components

12.2.1.8.1 Objectives. The objective will be to perform structural development tests on the primary structural subassemblies of the inner forward section and the forward section heat shield.

12.2.1.8.2 Test Plan. The apex section of the command module will be mounted on a test support fixture. The test specimen will be tested under the following loading conditions:

1. Crew couch attachment loads
2. Heat shield ejection loads
3. Main and drogue parachute deployment loads
4. Air load on heat shield and inner structure combination
5. Maximum heating
6. Burst pressure

Static loads will be applied by hydraulic struts. Deflections of the structure will be recorded at various increments of load by electrical deflection indicators. Electrical strain gauges will be mounted at critical locations and read at incremental load levels. Elevated temperatures will be applied by radiant heat lamps controlled by thermocouples attached to the specimen. Thermocouples will also be used to determine thermal gradients within the structure. Hot-air heating will be used, when applicable. Pressures will be applied to the components externally or internally, as required, with monitoring of deflection and strain readings.

12.2.1.8.3 Equipment. The following equipment will be required: load and pressure transducers, strain gauges, deflection devices and related recording equipment, hydraulic load struts, load and pressure application and reaction jigwork, load and pressure sequence valves and cyclic timers, thermocouples and recording equipment, radiant heating facility and/or hot-air heating as required for elevated temperatures and the attendant heat controllers, gas regulators, sequence valves and manifolds, GN_2 bottles, and LN_2 supply.

12.2.1.8.4 Facilities. S&ID facilities will be used.

12.2.1.8.5 Test Schedule. Tests are to be completed by March 1964.

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12.2.1.9 Command Module Window Test

12.2.1.9.1 Objectives. The objectives will be to determine the load-deflection characteristics of typical command module windows and seals at various temperatures in verification of the window material and design configuration and the strength properties and mode of failure of window material tested under thermal shock conditions.

12.2.1.9.2 Test Plan. The earth-landing orientation, docking, and crew hatch windows and their associated seals and frames will be installed in fixtures representative of their surrounding structure in the command module. The test specimens will be subjected to loads due to pressure differentials, which will be measured with pressure transducers and controlled with pressure regulators. Provisions will be made for pressure cycle testing using pressure sequence regulators and cyclic timers. These tests will be conducted under conditions of room temperatures, as well as thermal shock. Heat will be supplied to the specimens by radiant heat lamps. Cooling will be provided by liquid nitrogen. Hydraulic loading struts will be employed to supply external shear stresses to the supporting structure, as required.

12.2.1.9.3 Equipment. The testing will require deflection devices and support equipment, load and pressure transducers, fluid pressure sequence regulators and cyclic timers, hydraulic load struts, load and pressure application and reaction jigwork, thermocouples, recording equipment, and a radiant heating facility and attendant heat controllers for elevated temperatures.

12.2.1.9.4 Facilities. Window tests will be conducted by S&ID.

12.2.1.9.5 Test Schedule. Tests are to be completed by January 1964.

12.2.1.10 Storage Tank Components Test

12.2.1.10.1 Objectives. The objective will be to determine tank material characteristics, such as resistance to crack propagation, strength levels fabrication variables, and the structural integrity of each tank containing specified fluid-weight when it is subjected to vibratory forces.

12.2.1.10.2 Test Plan. The command module helium, fuel, oxidizer, crew oxygen, potable water, and center-of-gravity control water tanks will be subjected to combined pressure and temperatures similar to those already described. In addition, these tanks containing the specified fluid-weights

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will be subjected to vibratory loading, utilizing vibration test exciters. Vibration loading will be controlled with cathode followers and recorded with accelerometers.

The highly pressurized fuel, oxygen, and helium tanks will be drop-tested to generate the landing impact shock loads of earth landings. Drops will be made in varied tank attitudes and on varied surfaces to achieve the proper load-time relationship. Accelerometers will be used to record the tank strains.

12.2.1.10.3 Equipment. The testing will require gas regulators, sequence valves and manifolds, GN_2 bottles and LN_2 supply, accelerometers, cathode followers, amplifiers, a recording oscillograph, a voltimeter, a vibration load exciter, and related power and control equipment.

12.2.1.10.4 Facilities. Tank tests will be conducted by the supplier and by S&ID.

12.2.1.10.5 Test Schedules. Tests are to be completed by December 1963.

12.2.1.11 Command Module Static Thermal-Structural Test

12.2.1.11.1 Objectives. The purpose of the tests are (1) to perform full-scale design evaluation of the spacecraft command module inner structure in combination with the heat shield substructure without ablator, under conditions commensurate with the entry trajectories; (2) to verify the performance of the over-all heat shield structural attachment system design and to ascertain the detailed interaction of the various slip joints and frames; (3) to verify the structural and thermal analyses pertaining to the performance of the inner cabin heat protection capabilities as influenced by the attachment mechanism and related insulating materials and installation clearances.

In order to perform a realistic test of the command module structure, data from subassembly component tests will be used to obtain testing information applicable to the full-scale test and which would preclude premature failure of the command module. Information for installation of strain and deflection gauges; measurement of strains, deflections, and temperatures; and thermal simulation techniques will be evaluated.

The temperature time history for the significant design entry trajectories will be simulated on the base C/M heat shield substructure. These temperatures will duplicate those which occur at the ablator-steel substructure interface at entry following lunar mission.

12.2.1.11.2 Test Plan. The AFRM 005 command module will be mounted in a test fixture at the tower attachments and will be completely surrounded and heated by an independently supported radiant heat lamp oven. The heat-shield surface will be coated with a lamp black solution to improve the heat transfer. Thermocouple installations in the substructure will control the heat output from the radiant heat lamps for the test temperature time histories programmed on the radiant heating computers.

Other thermocouples will monitor the backface, inner structure, and thermal-structural slip-attachment temperatures. Strains and deflections will be recorded in critical areas and monitored for test control. Performance of the slip attachments will be verified by deflection methods.

12.2.1.11.3 Equipment. The equipment needed will consist of strain gauges, deflection devices, and related recording equipment; C/M supporting jigwork and radiant heating oven with attendant temperature controllers; thermocouples and recording equipment; and GSE for transport and hoisting of the command module.

12.2.1.11.4 Facility. The S&ID laboratory at Downey, California, will be used in the test program.

12.2.1.11.5 Test Schedule. Testing will start 1 April 1965 and be complete testing by 1 August 1965.

12.2.1.12 C/M - LEM Docking Configuration - Structural Element/Subassembly Tests

12.2.1.12.1 Objectives. The design integrity of C/M structural elements and subassemblies that have not been previously tested will be determined prior to incorporation into design of the complete C/M.

12.2.1.12.2 Test Plan. Structural elements and subassemblies will be subjected to environments similar to expected flight conditions. Structural boundary conditions will be simulated where necessary to obtain load paths and magnitudes of the proposed C/M flight configuration. Tests will be conducted on docking mechanism attachment structure, hatches, and other subassemblies. Instrumentation requirements for each element/subassembly test will be selected so that the integrity of the design may be determined.

12.2.1.12.3 Equipment. The following equipment will be required to perform the C/M (LEM docking configuration) structural element/subassembly tests.

1. Strain, deflection, and temperature transducers with applicable recording equipment

2. Hydraulic load struts with pressure supply and regulating equipment

3. Radiant heat lamps with supporting fixtures, power source, and controls

4. Load application and reaction fixtures

12.2.1.12.4 Facilities. S&ID facilities will be used.

12.2.1.12.5 Test Schedule. All tests will be completed by 1 May 1965.

12.2.1.13 C/M - LEM Docking Configuration, Docking and Latching Mechanisms Structural Tests

12.2.1.13.1 Objectives. Mechanisms used in the C/M-S/M-LEM docking operation and in latching the LEM to the C/M will be evaluated for critical flight structural loading environments.

12.2.1.13.2 Test Plan. LEM inertial loads and appropriate temperatures and pressures will be applied to the docking mechanism while oriented at various angles and extension lengths from the C/M. Structural integrity of the latching mechanism will be determined for misalignment during docking, for flight inertial loads, and for temperature and pressure environments. Tests will be performed on complete docking and latching mechanism assemblies installed in a simulated spacecraft C/M structure. Instrumentation will monitor all major structural components of the mechanisms.

12.2.1.13.3 Equipment. The following equipment will be required to perform the C/M docking and latching mechanisms structural test.

1. Strain, deflection, pressure, and temperature transducers with applicable recording equipment

2. Hydraulic load struts with pressure supply and regulating equipment

3. Radiant heat lamps with supporting fixtures, power source, and controls

4. Load application and reaction fixtures

12.2.1.13.4 Facilities. S&ID facilities will be used.

12.2.1.13.5 Test Schedule. All Tests will be completed by 15 January 1966.

12.2.1.14. C/M - LEM Docking Configuration, Structural Tests

12.2.1.14.1 Objectives. The structural integrity of the C/M structure (LEM docking configuration) will be evaluated for all critical flight conditions.

12.2.1.14.2 Test Plan. The C/M structure will be evaluated for critical environments encountered during the CSM-LEM docking operation, during midcourse maneuvers after LEM vehicle is latched to the C/M, and for parachute deployment loads. Test article shall consist of spacecraft C/M structure (less ablator) from approximately station $X_c = 66.0$, forward. Loads will be applied to the test article through a structure which simulates the LEM vehicle rigidity and interface and by flight configuration parachute harness assembly. Appropriate flight pressure and temperature environments will be simulated. Instrumentation will be selected such that the integrity of the structure may be evaluated for each loading environment.

12.2.1.14.3 Equipment. The following equipment will be required to perform the C/M (docking configuration) structural tests.

1. Strain, deflection, pressure, and temperature transducers with applicable recording equipment
2. Hydraulic load struts with pressure supply and regulating equipment
3. Radiant heat lamps with supporting fixtures, power source, and controls
4. Load application and reaction fixtures

12.2.1.14.4 Facilities. S&ID facilities will be used.

12.2.1.14.5 Test Schedule. All tests will be completed by 15 February 1966.

12.2.2 Analytical Methods Verification Tests

12.2.2.1 Objectives

The evaluation of analytical methods will be made in the following areas: buckling, thermal stress, stress-deflection relationship, creep, and micrometeorites.

12.2.2.2 Test Plan

The test articles for the analytical methods verification tests will consist of:

1. Shells of revolution (spherical, cylindrical, and conical) of monocoque, sandwich, and stiffened construction with and without cutouts. (The loadings will be thermal gradients, axial compression, external pressure, bending, torsion, and concentrated loads. The data received will pertain to general instability loads, stresses, and deflection relationships.)

2. Flat sandwich panels tested for local instability loads (wrinkling and dimpling under combined loadings)

3. Honeycomb cores loaded to examine properties of curvature, combined loads, and shear testing methods

4. Sandwich structure joints with different types of close-out members subjected to general loading

5. Creep specimen for redundant frame and frame material strength properties

6. Micrometeorite specimen flat panels, prestressed

7. Bond stress distribution in laminar panels and lap joints

Shells of revolution of sandwich construction will be tested with different radius-to-thickness ratios and with core material of different shear rigidities. Sandwich shells of revolution of frame and longeron construction with cutouts will be tested. Test conditions will involve loadings that produce instability failures in the elastic range of the particular material used. Thermal gradients will be applied longitudinally and circumferentially. Nonsymmetrical loadings will be introduced. Load, strain, deflection, and buckle pattern dimensions and characteristics will be obtained. Also, the type of failure will be noted. Photographs will be taken of typical specimen failures and motion pictures will be taken in some tests to record specimen behavior.

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Local instability of sandwich construction will be determined by varying honeycomb core, cell size, and density. Flat panels of sandwich construction will be sized, so that failure will be initiated due to local instability. Combined loads, in plane, for a number of different load ratios will be applied to the test panels. Loads, load ratios, strain, and description of failure will be noted.

The mechanical properties for curved honeycomb sections will be determined for a number of different curvatures. The variation of shear and compressive properties with curvature will be established. A particular core cell size and density will be selected for the test. Block shear and parallelogram testing methods will be used to determine the shear properties. The applicability of each method in determining the shear properties of flat honeycomb sections will be determined.

Curved panels of sandwich construction with different types of end close-outs will be tested. The test specimen will be loaded under a specified load condition and the stresses in the joints and close-out members will be determined.

A redundant frame structure subjected to elevated temperature and concentrated loads will be tested. Specimens of the material used to construct the frame will be tested to obtain creep characteristics. The load and strain for a given temperature as a function of time will be determined. This information will be used in the frame analyses. The deflection and stress distribution for the redundant frame due to creep will be found.

Flat metal panels will be loaded biaxially and then subjected to simulated micrometeorite impact in a hypervelocity gun. The amount of damage as well as any apparent crack propagation will be noted and evaluated. The test specimens will be instrumented so that the stress distribution before and after impact can be determined.

12.2.2.3 Equipment

Equipment required will include load and pressure transducers, strain and deflection gauges, hydraulic load struts and pressure regulating units, load and pressure applying and reacting jigwork, load and pressure sequence valves and cyclic timers, radiant heat lamps, thermocouples, and recording equipment.

12.2.2.4 Facilities

S&ID facilities will be used.

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12.2.2.5 Test Schedules

Test schedules will be determined at time of final design freeze.

12.2.3 Meteoroid Shielding

12.2.3.1 Objectives

This program is divided into two phases. Phase I (analysis verification) will verify the validity of the analysis effort by conducting a comprehensive test program comprising a parametric study to evaluate meteoroid and target characteristics. Phase II (design verification) will verify the effectiveness of the command module and service module structural design when evaluated for meteoroid shielding and crater damage to the ablative heat shield.

12.2.3.2 Test Plan

In Phase I, the penetration mechanics and phenomena assumed in the analytic model will be verified by simulated meteoroid impact, using various projectiles on a variety of targets. Projectiles will vary in size, density, and velocity. Targets will vary in material, density, and strength characteristics and in thickness and design. Target design of multi-wall construction will vary in number of sheets, sheet spacing, and filler materials. Data will also be collected on the meteoroid environment from astronomical observation and from earth-launch satellites and deep space probes for further verification.

In Phase II, data obtained from Phase I will be used to verify prototype design and to develop test particles with meteoroid charcteristics. Tests similar to Phase I, but using these test particles, will be conducted for proof-testing of prototypes of the command module conical wall section, command module heat shield section, service module cylindrical wall section (including radiators), service module aft heat shield component, and pressurized tank construction.

12.2.3.3 Equipment

Instrumentation will be required to determine crater size and diameter, impact momentum, spall effects, projectile dispersion after impact, flux density versus momentum consistent with the threshold of sensivity, and meteoroid mass and density.

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12.2.3.4 Facilities

The General Motors Corporation, Santa Barbara facility, will provide a hypervelocity impact gun and ballistic range.

12.2.4 Dynamic Effects of Mass Loading Tests

12.2.4.1 Test Objectives

1. To investigate the validity of the current concept, established in specification MIL-E-5272 C, that vibration response intensity is reduced as equipment weight is increased

2. To determine the dependence of local structural response on various parameters, such as weight, stiffness, phase relationship, damping, forcing frequency, and amplitude

3. To evaluate the theoretical methods of analysis and determine the necessary parameters to compute the acoustic and vibration response of structures

4. To develop acoustic and vibration control techniques through investigation of structural damping devices

12.2.4.2 Test Plan

With minimum man-hours, with available test time and facility, and with already existing equipment, vibration and acoustic tests on panels of various materials and construction will be performed. The test program is outlined as follows:

1. Effect of concentrated rigid mass on the natural frequencies, acceleration responses, amplitude responses, damping, stiffness, and flexibility of the support structure

2. Effect of concentrated rigid mass on the shaker output

3. Mass and dynamic attenuation study of a generalized two-degree-of-freedom system. (This includes the investigation of mass coupling effects at the primary natural frequency on the prime structure, the secondary structure, and the integrated system. The mass coupling effect will also be investigated at various frequencies other than resonances and for in-phase and out-of-phase conditions.)

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4. Effect of mass coupling on the shaker output
5. Effect of stringers
6. Steady sinusoidal acoustic evaluation
7. Nonsteady sinusoidal acoustic evaluation
8. Steady random frequency broad-band acoustic evaluation
9. Nonsteady random broad-band acoustic evaluation
10. Comparison of the vibration and acoustic responses of isotropic plates and sandwich plates

12.2.4.3 Test Requirements

The following test data are required

1. Vibration intensity versus frequency (5 to 2000 cps) at several points on panel and fixture
2. Damping
3. Phase relationship
4. Acoustic pressure

12.2.4.4 Equipment

1. Aluminum panel, 16 by 18 inches
2. Aluminum panel with stiffness attached, 16 by 18 inches
3. Sandwich honeycomb panel (flat), 16 by 18 inches
4. Sandwich honeycomb (curved), 16 by 18 inches
5. Rigidamp panels (free sample), 16 by 18 inches
6. Stringers
7. Aqua-plas (free sample)

12.2.4.5 Facilities

S&ID Engineering Development Laboratories are being used.

12.2.4.6 Test Schedule

Formal testing was completed 15 January 1963. However, additional confirmatory tests are required for data correlation. The scheduled completion date is 1 April 1963 for these tests.

12.2.5 Spacecraft Modal and Vibration Transmissibility Test

12.2.5.1 Objectives

To determine the free-free bending modes and first torsional modes and the longitudinal modes and longitudinal vibration transmissibility of the spacecraft configuration at sea-level atmospheric conditions.

12.2.5.2 Test Plan

Two configurations will be tested:

Configuration 1 - Abort configuration, command module and LES. Test article will be oriented vertically and suspended from bottom of command module.

Configuration 2 - Spacecraft configuration, command module and service module. Test article will be oriented vertically and supported at the service module base.

Both configurations will be subjected to a slow sinusoidal excitation in the 3- to 400-cps frequency range of interest. Dwells will be conducted at predominate response frequencies to confirm modes. The structure must be instrumented to determine modes and secondary structural response.

12.2.5.3 Test Requirements

Test jigs will not influence the free-free body modes within the 3- to 400-cps frequency range of interest. The following modes and transmissibility data are required.

1. Lateral bending modes of both the abort and spacecraft configurations

2. Torsion modes of both the abort and spacecraft configurations in the 3- to 100-cps frequency range

[redacted]

3. Longitudinal modes of only the spacecraft configuration (Apply longitudinal vibration excitation through the base structure of service module)

4. Determine longitudinal vibration transmissibility of spacecraft configuration plus adapter section (Evaluate vibration transmission paths and predominant local responses)

12.2.5.4 Equipment

1. Displacement, velocity, and vibration instrumentation systems

2. Hydraulic vibration excitation system

3. Magnetic tape recording and visual data display capability

4. On-site data reduction capability to confirm modes prior to excitation or configuration changes

12.2.5.5 Facilities

S&ID facilities will be used.

12.2.5.6 Test Schedule

The test schedule is contingent upon selection of a vehicle for the test.

12.2.6 Limited Combined Module Static Tests - S/M and S-IV Adapter (AFRM 004)

12.2.6.1 Objectives

The structural integrity of the service module and S-IV adapter will be determined. Structures will be subjected to a single major load condition and also other load conditions which cannot be reasonably imposed during subsequent combined module static tests with command module. General stress distribution, strength, stiffness, and load deflection will be determined. Analysis methods will be evaluated, and areas that require strengthening or design improvement will be located.

12.2.6.2 Test Plan

Test will be conducted on a service module and S-IV adapter which are similar structurally to flight hardware. Loads will be applied to the service module at the S/M-C/M interface by a fixture simulating the command module. Major internal inertial forces will be applied and air

[redacted]

[redacted]

loads simulated as required. All applied loads will be reacted at the aft splice of the adapter. The combined modules will be tested in a static test facility which will also be used for subsequent combined module test with command module. Sufficient strain and deflection instrumentation will be used to determine general stress distributions and deformations. Data will also be monitored during testing in order to anticipate premature structural failure.

12.2.6.3 Equipment

The following equipment will be required to perform the limited combined module tests.

1. Strain and deflection transducers with applicable recording equipment
2. Hydraulic load struts with pressure supply and regulating equipment
3. Load application and reaction fixtures

12.2.6.4 Facilities

S&ID facilities will be used.

12.2.6.5 Test Schedule

All tests are to be completed by 1 January 1965.

12.2.7 Structural Component Tests

12.2.7.1 Objectives

The service module components will be subjected to the critical design load conditions and to the load required to cause failure. Stress distribution, strength, stiffness, load deflection, and failure mode characteristics will be determined. Analysis methods will be evaluated, and sufficient information will be evaluated, and sufficient information will be obtained to make design improvements, if required.

12.2.7.2 Test Plan

Tests will be conducted on the following articles: aft bulkhead, outer-shell structure (honeycomb), radial shear web, miscellaneous structural parts, and SPS tank door. The service module component test

[redacted]

specimen will be mounted in a support fixture which simulates the component installation on the module. Flight and inertia loads will be applied by hydraulic loading struts. Strain gauges will be mounted at critical locations on the specimen structure to measure stress levels during tests.

12.2.7.3 Equipment

Load and pressure transducers, strain and deflection gauges, hydraulic load struts and pressure regulating units, load and pressure applying and reacting jigwork, load and pressure sequence valves, cyclic timers, and recording equipment will be required.

12.2.7.4 Facilities

S&ID facilities will be used.

12.2.8 Pressure Vessel Tests

12.2.8.1 Objectives

The service module pressure vessels will be subjected to combined inertia and pressure load, cyclic pressure, vibration, and burst load tests. Stress distribution, strength, stiffness, creep, and failure mode characteristics will be determined. Analysis methods will be evaluated, and sufficient information will be obtained to make design improvements, if required.

12.2.8.2 Test Plan

Four tanks of each type will be subjected to various combinations of inertia load, static pressure, cyclic pressure, and vibration testing prior to design burst. The temperature environment will be considered, if critical. When cryogenic fuels are used, the tank will be pressurized with liquid nitrogen. Strain gauges will be installed at critical areas on the structure, and measurements will be recorded at design pressures.

The articles to be tested and the quantity required are presented in the following listing:

Type	Item	Proof Tests	Qualification Tests
SPS	Cylindrical oxidizer tanks (51 in. diam)	All	4
SPS	Cylindrical fuel tanks (45 in. diam)	All	4

Type	Item	Proof Tests	Qualification Tests
RCS	Cylindrical oxidizer tanks (12.6 in. diam)	All	4
SPS	Spherical helium tanks (45 in. diam)	All	4
RCS	Spherical helium tanks (9 in. diam)	All	4
ECS	Spherical liquid oxygen tanks (28 in. diam)	All	4
ECS	Spherical liquid nitrogen tanks (14 in. diam)	All	4
ECS	Spherical liquid hydrogen tanks (30 in. diam)	All	4
	Cylindrical water tank (10 in. diam)	All	4
RCS	Cylindrical fuel tanks (12.6 in. diam)	All	4

12.2.8.3 Test Facilities

The tests will be conducted by the following:

Allison Division of GMC	SPS fuel and oxidizer
Airite Division of Electrada Corporation	SPS helium
Bell Aircraft	RCS oxidizer and fuel
Menasco	RCS helium
Airesearch	Water tank
Beech	ECS liquid hydrogen and oxygen

12.2.8.4 Equipment Required

Standard vessel pressure test equipment will be required.

12.2.9 Launch Escape Tower Tests

12.2.9.1 Launch Escape Tower Static Structural Tests

12.2.9.1.1 Objectives. Static evaluation tests will be performed on the spacecraft launch escape tower under simulated design conditions of thrust, aerodynamic, and inertia loads. These tests will verify the structrual integrity of the tower, provide load deflection characteristics and stress data in support of the structural analysis, and indicate the load capability, possible instabilities, and mode of failure.

12.2.9.1.2 Test Plan. The spacecraft launch escape tower will be mounted in a structural testing support fixture to simulate the attachment of the tower to the command module. A loading fixture will be installed on the tower to simulate the attachment of the launch escape rocket motor. Provisions will be made to apply rocket thrust loads (main thrust motor and pitch control motor) to the loading fixture and to apply other external loads to the tower simulating air and inertia loads. The static loads will be modified to allow for the temperature effects on the structure. Structural loads will be applied with hydraulic loading structures, and deflectors will be recorded.

12.2.9.1.3 Equipment. Load cells, deflection devices, strain gauges, and accompanying recording equipment will be required. Also required will be hydraulic struts, simulated tower adjacent structures (such as the main rocket motor case and the command module), and test jigwork.

12.2.9.1.4 Facilities. S&ID facilities will be used.

12.2.9.1.5 Test Schedules. Tests are to be completed by August 1963.

12.2.9.2 Launch Escape Tower Static Rocket Firing Tests

12.2.9.2.1 Objectives. Structural and dynamic evaluation tests will be performed on the launch escape tower system under actual conditions of rocket thrust loads, vibration, and exhaust temperature. These tests will verify the structural integrity and design soundness of the launch escape system, determine heat paths and suitability of insulation materials, determine vibration levels of the launch escape motor and the vibration transmission characteristics of the launch escape tower, and determine launch escape system induced stresses at selected locations.

12.2.9.2.2 Test Plan. The spacecraft launch escape system (consisting of the tower structure, structural skirt, and a launch escape motor) will be mounted vertically on a test stand supporting jig at the subcontractor facility. At least one static rocket firing will be made. Stresses in members will be measured with strain gauges. Triaxial accelerometers will measure tower vibrations at specified locations. Thermocouples and heat flux meters installed on the tower will measure temperature and heat flow rate. Microphones will be used to measure sound pressure levels.

12.2.9.2.3 Equipment. A mobile instrumentation trailer or existing ground installation required with provision for remote operation of data acquisition equipment are required.

12.2.9.2.4 Facilities. S&ID and Lockheed Propulsion Company facilities will be used.

12.2.9.2.5 Test Schedules. Tests were completed in April 1963.

12.2.9.3 Launch Escape Tower Structural Component Tests

12.2.9.3.1 Objectives. The load deflection characteristics of welded tube joints at room and elevated temperatures will be determined in verification of the tubing materials, welding methods, and joint design selected for the full-scale launch escape tower. Design development tests of a welded tube truss-beam, simulating a portion of the tower, will be performed at room temperature to determine the joint-and-tubing strength properties and modes of failure and to verify the welding techniques and producibility of a large structure.

Design development tests of the attachment fittings and adjacent structure for both the tower-to-command module and the tower-to-main rocket motor, under conditions of simulated design loads and room and elevated temperatures, will be performed. These tests will demonstrate the structural integrity of the fittings and supporting structure. The physical and heat transfer characteristics of candidate ablative materials applied to the external surface of steel tubes will be evaluated by subjecting specimens to a rocket exhaust.

12.2.9.3.2 Test Plan. Tests will be conducted on typical welded tubing cluster-joints (with and without gussets), welded tubing truss structure, attachment fittings, and adjacent structure for both the tower-to-command module and the tower-to-main rocket motor. The various test specimens of the tower, as described above, will be supported in holding fixtures to simulate the particular component attachment within the complete launch escape tower structure. Tests will be conducted at room temperature and at elevated temperatures up to 600 F. The test loads will be applied to the specimens with a testing machine or struts. Heat will be applied, as required, with radiant heat lamps or with hot-air blowers. Deflection indicators will be used to measure specimen deflection. Strains will be measured with high-temperature strain gauges. Thermocouples will be used to measure and control specimen temperatures during the elevated temperature runs.

12.2.9.3.3 Equipment. Required will be load cells, deflection devices, strain gauges, and attendant recording apparatus, testing machines or hydraulic struts, thermocouples, temperature recorders, elevated temperature chambers and related controllers, and metallurgical examination equipment and jigwork.

[redacted]

12.2.9.3.4 Facilities. S&ID facilities will be used for the structural component tests.

12.2.9.3.5 Test Schedules. Tests were completed in May 1963.

12.2.10 Combined Module Tests

12.2.10.1 Combined Module Static Tests - C/M, S/M, and S-IV Adapter

12.2.10.1.1 Objectives. The structural integrity, intermodular compatibility, and structural analysis of the command module, service module, and S-IV adapter will be evaluated for all major boost phase flight load conditions. Stress distribution, load/deflection characteristics, and strength will be determined.

12.2.10.1.2 Test Plan. Tests will be conducted on the service module and S-IV adapter used in the limited combined-module tests and a command module structurally identical to flight hardware. Loads will be applied to the command module through a dummy launch escape tower and interstructure to obtain C/M-S/M interface loads. Inertial and air loads acting on the service module and adapter will be simulated. Strain, deflection, and pressure transducers will be installed at all critical points and data recorded as a function of load increment.

12.2.10.1.3 Equipment. The following equipment will be required to perform the combined module tests.

1. Strain, deflection, and pressure transducers with applicable recording equipment
2. Hydraulic load struts with pressure supply and regulating equipment
3. Pressure bags or tension pad fixtures with controls and supporting fixtures
4. Load application and reaction fixtures

12.2.10.1.4 Facilities. S&ID facilities will be used.

12.2.10.1.5 Test Schedule. Tests are to be completed by 1 April 1965.

12.2.10.2 S-IV B Adapter Section Structural Elements Tests

12.2.10.2.1 Objectives. The design integrity of primary structural subassemblies and compatibility with the complete adapter section structure will be determined. Analysis of test data will assist in evaluating and developing the design of structural elements prior to incorporating them into design of major subassemblies.

12.2.10.2.2 Test Plan. Structural elements of the adapter section will be subjected to load and pressure environments similar to expected flight conditions. Tests will be performed on manufacturing joints, field splices, cut-outs, and other structural discontinuities. Test fixtures and methods of load application will accurately simulate proposed flight configuration load paths and magnitudes. Instrumentation requirements will be determined for each structural element tested, so that the design may be evaluated and, if necessary, developed from analysis of test data.

12.2.10.2.3 Equipment. The following equipment will be required to perform the LEM adapter section structural elements tests.

1. Strain and deflection transducers with applicable recording equipment
2. Hydraulic load struts with pressure supply and regulating equipment
3. Load application and reaction fixtures

12.2.10.2.4 Facilities. S&ID facilities will be used.

12.2.10.2.5 Test Schedule. Tests are to be completed by 1 September 1964.

12.2.10.3 S-IVB Adapter Section Structural Subassembly Tests

12.2.10.3.1 Objectives. Data obtained from tests on major structural subassemblies will be analyzed to evaluate and develop subassembly design prior to incorporation into complete adapter section structure design. Elevated temperature strength properties of the adapter shell honeycomb material will be determined.

12.2.10.3.2 Test Plan. Major structural subassemblies of the adapter section will be subjected to load and pressure environments simulating expected flight conditions. Strain and deflection instrumentation will be selected, such that test data may be used to evaluate the interaction of previously tested primary structural elements and over-all design of subassembly. Uniaxial load tests will be performed on small panels (12 inches

x 12 inches) of adapter shell honeycomb material at temperatures up to 460 F. Face sheet strain will be measured as a function of static load and temperature.

12.2.10.3.3 Equipment Requirements. The following equipment will be required to perform the LEM adapter structural subassembly tests.

1. Strain, deflection, and temperature transducers with applicable recording equipment

2. Hydraulic load struts with pressure supply and regulating equipment

3. Radiant heat lamps with supporting fixtures, power source, and controls

4. Load application and reaction fixtures

12.2.10.3.4 Facilities. S&ID facilities will be used

12.2.10.3.5 Test Schedule. Tests are to be completed by 1 November 1964.

12.2.10.4 S-IVB Adapter Section Structural Tests

12.2.10.4.1 Objectives. The structural integrity of the LEM adapter section will be evaluated for all Apollo missions. Test section will be subjected to tests which simulate all major aerodynamic and inertial load conditions, and corresponding temperature and pressure environments. Load magnitudes for one condition will be increased until failure occurs. Stress distribution, strength, stiffness, deflection, and failure mode data will be recorded and analyzed.

12.2.10.4.2 Test Plan. Tests will be conducted on a LEM adapter section structurally identical to flight hardware. External insulation, pyrotechnic separation systems, and all nonstructural payload items will be deleted from test article. Loads will be applied to the adapter section at the forward field splice through a simulated section of the service module approximately four feet in length. Loads will be reacted at the aft field splice through a simulated S-IVB instrument unit. Simulated service module section and instrument unit will be used to ensure flight-condition load paths. LEM inertial loads will be applied to the test section by a spider beam fixture which simulates the structural rigidity and interface of the LEM at the

[redacted]

attachment points. Differential pressure across the section panels and aerodynamic flight loads will be simulated by pressure bag fixtures. Static loads will be adjusted to compensate for elevated flight temperatures.

The adapter section will be tested in a static test facility which has the capability of reacting all applied axial loads, shear loads, and bending moments. Test fixtures will be designed to permit accurate simulation of longitudinal loads, lateral loads, bending moments, and pressure distributions of test flight conditions without affecting the structural properties of the test section.

Strain, deflection, and pressure transducers will be installed at all critical points and data recorded as a function of load increment. Instrumentation will be sufficient to determine over-all stress distributions and deformation of the test section. Data will also be monitored during testing in order to anticipate structural failure.

12.2.10.4.3 Equipment. The following equipment will be required to perform the LEM adapter section structural tests.

1. Strain, deflection, and pressure transducers with applicable recording equipment

2. Hydraulic load struts with pressure supply and regulating equipment

3. Pressure bags, support fixtures, pressure supply, and controls

4. Load application and reaction fixtures

12.2.10.4.4 Facilities. S&ID facilities will be used.

12.2.10.4.5 Test Schedule. Tests are to be completed to design limit levels by 15 November 1965 and to design ultimate levels by 15 July 1966.

12.2.11 GSE Handling Equipment Structural Test

12.2.11.1 Objectives

The objectives of the test are to provide design verification and structural qualification for each critical item of handling equipment.

[redacted]

12.2.11.2 Test Plan

Qualification by proof test or destruction test will be performed on the following items as noted.

Proof Test

Aircraft loading set and C/M support
Spacecraft cleaning positioner
Spacecraft vertical transport vehicle and spacecraft support
C/M, S/M, and adapter weight and balance fixture

Destruction Test

S/M and adapter sling
Spacecraft sling (without LES)
Spacecraft sling (with LES)
LES horizontal handling sling

12.2.11.3 Equipment

Equipment required includes the test specimen, laboratory fixtures, instrumentation, and recording equipment.

12.2.11.4 Facilities

S&ID laboratory facilities will be used to perform the tests.

[redacted]

13.0 MECHANICAL AND ORDNANCE DEVICES

13.1 SCOPE

The mechanical and ordnance devices test program encompasses all development and design testing required to verify the ability of the Apollo spacecraft mechanical and ordnance devices to withstand critical mission environments and loads. The primary program test areas include development and evaluation tests on components and complete units of the following:

Command module
Service module
Spacecraft adapter
Launch escape tower
Earth landing system

The final design verification of separation devices will be performed in conjunction with structural tests as described in Section 12.0, Structural Tests.

13.2 INDIVIDUAL TESTS

13.2.1 Separation Subsystem—Separation of Command Module From Service Module

13.2.1.1 Objectives

The operational characteristics of a subsystem in its initial design configuration will be determined by testing under simulated environmental and critical loading conditions. Data obtained from the tests will be used to improve the subsystem by modification or redesign. In particular, the investigation will include the disconnect characteristics of the tension ties, electrical and environmental interface disconnects, and the operation of pyrotechnic release devices. The time required to effect complete intermodule release will also be determined.

13.2.1.2 Test Plan

Detail tests will be run on each of the separation points having the electrical and environmental interface disconnects. Separate cycles will be run under various environmental and loading conditions. Instrumentation will be employed to measure release time, phasing of electrical and environmental structural disconnects, and other functional parameters. Complete

[redacted]

subsystem tests will be run to determine the characteristics of pyrotechnic separation devices, the phase characteristics, and the time required to effect complete intermodular release. Articles to be tested are boilerplate and prototype devices. Purchased items are included.

13.2.1.3 Equipment

A skeletal jig will be required. This jig will provide the attachment and a structural simulation of the actual rigidity of the command module and service module structural interface.

13.2.1.4 Facilities

S&ID facilities will be used.

13.2.2 Separation Subsystem — Service Module from Adapter

13.2.2.1 Objectives

The objective is to determine the operational characteristics of the subsystem in its initial design configuration by testing it under simulated environmental and loading conditions. Data obtained from these tests will be used to improve the subsystem by modifying or redesigning. In particular, the investigation will include the structural separation characteristics, initiation, and sequencing devices. The time required to effect complete intermodular release will be determined.

13.2.2.2 Test Plan

Detail tests will be run on structural samples that are identical to the honeycomb in every respect but panel size and on the electrical interface disconnect. Separation tests will be run under critical environmental and loading conditions. Approximately five full-scale models of the adapter will be used for system testing. Instrumentation will be employed to measure separation time, the phasing of electrical structural disconnect, and other functional parameters. Complete subsystem tests will be run to determine characteristics of initiation and sequencing devices and the time required to effect complete intermodular release. Articles to be tested are structural samples and prototype structure at the separation interface. Purchased items are included.

13.2.2.3 Equipment

A skeletal jig will be required. This will provide the attachment and support for prototype structure in the vicinity of the various locations where separations will occur.

13.2.2.4 Facilities

S&ID facilities will be used.

13.2.3 Separation Subsystem — Escape Tower from Command Module

13.2.3.1 Objectives

Design analysis of the release and separation of the escape tower from the command module is to be verified. Environmental and loading conditions will be simulated.

13.2.3.2 Test Plan

The ease with which the escape tower can be attached to the command module will be determined. The feasibility of access for connecting and disconnecting the umbilical electrical connector will be established. The adequacy of the clearance of tower legs with the command module at the critical separation angle will be verified. Separation tests will be conducted under actual load conditions to determine the time required for complete separation of the escape tower, as well as to evaluate the disengagement of the umbilical connectors.

13.2.3.3 Equipment

A skeletal jig of the lower portion of the escape tower and a structural simulation of the upper cone of the command module will be needed. These jigs must duplicate the prototype configuration with respect to accessibility, rigidity, and detail design where the escape tower and command module are attached.

13.2.3.4 Facilities

S&ID facilities will be used.

13.2.4 Crew Couches and Shock Attenuation Subsystem

13.2.4.1 Objectives

Data will be provided for evaluation and modification of the dynamic characteristics of the shock attenuation subsystem wherever necessary. The functional performance of couch adjustments, shock strut adjustments, lockout devices, etc., will be checked and evaluated. The structural integrity of the complete subsystem will be proved.

13.2.4.2 Test Plan

The instrumented and assembled prototype crew couches and shock strut attenuation subsystem will be installed in the drop test fixture. Weighted mannikins or other suitable mass simulators will be placed on the couches and restrained in the proper manner. Progressive drop tests will be made from various heights and at attitudes that will produce the critical loads. Data from these tests will be analyzed to evaluate the dynamic characteristics of the shock attenuation subsystem in all modes of operation. Tests will be performed to limit loads. The proper functioning of shock struts, adjustments, lockout devices, etc., will be checked. Structural requirements may make it necessary to continue tests to the point at which failure occurs. Static load tests will be performed on parts of the couches and on the shock attenuation subsystem. Deflection measurements from simulated steady-state g loadings will be made and compared with design values. Three complete crew couch assemblies and the shock strut attenuation subsystem will be tested.

13.2.4.3 Equipment

Drop test fixtures and related support equipment will be needed, as well as typical strain gauge and oscillograph recording equipment and high speed motion picture equipment, for use on the drop tests.

13.2.4.4 Facilities

S&ID facilities will be used.

13.2.5 Pressure Compartment Access Testing

13.2.5.1 Objectives

One aim of this testing is to define the most desirable of several reasonably convenient means of egress or ingress with respect to the command module. The means selected should result in a minimum loss of the environmental integrity of the command module under conditions of design mission (launch, long-term exposure to the space environment, entry, etc.). A second aim is to determine the general design characteristics (unlocking forces, travels, etc.) of the preferred systems during exposure and after exposure to appropriate environmental conditions. A third aim is to verify the capability of the subsystems to maintain the desired environmental integrity throughout the conditions encountered during the missions.

13.2.5.2 Test Plan

Mechanisms will be cycled under appropriate environmental conditions, and forces, travels, etc., will be recorded. Test assemblies will be exposed to critical environmental conditions. Performance characteristics (leakage rates, etc.) will be recorded. Preferred subsystems will be determined and selected on the basis of performance. The subsystem will be cycled during and after exposure to all critical environmental conditions. The major characteristics (forces, travels, etc.) of the air lock and hatches, as well as those of the latching and actuating mechanisms, will be recorded and compared to design requirements.

13.2.5.3 Equipment

Supporting structure and a sealed structure across the inside of the hatch will be needed to develop a pressure differential in a vacuum chamber. Fixtures will be required to support components and to simulate spacecraft subsystems. Vacuum chamber, radiant heating panels, standard laboratory equipment for measuring and recording leakage rates, forces, etc., will also be needed.

13.2.5.4 Facilities

S&ID facilities will be used.

13.2.6 Positioning Devices

13.2.6.1 Objectives

Testing will determine, under simulated environmental conditions, the characteristics of the initial subsystem configurations of the telescope deployment-actuation system and the filter subsystem. Assurance will be obtained that the prototype subsystems will perform their functions satisfactorily during and after exposure to the appropriate environmental conditions.

13.2.6.2 Test Plan

Mechanisms will be cycled to critical environmental conditions during and after exposure. Forces, travels, clearances, etc., of a simulated telescope, without optics, but with required mechanisms, operation of window covers (simulated or test specimen), and operation of filter actuating mechanisms will be recorded.

[redacted]

13.2.6.3 Equipment

Supporting structure simulating the actual structural rigidity in the region of the subsystem, as well as jigs, will be needed, as required, to mount support structure for the test systems. Standard laboratory equipment will be required for measuring forces, travels, deflections, etc. Means for simulating appropriate environmental conditions, such as a vacuum chamber, radiant heating panels, etc., will be supplied.

13.2.6.4 Facilities

S&ID facilities will be used.

13.2.7 Forward Compartment Cover (Heat Shield) Release Subsystem

13.2.7.1 Objectives

This test will develop the subsystem used to retain the forward compartment cover and eject it prior to main parachute deployment under all possible flight conditions.

13.2.7.2 Test Plan

The test jig will be installed in a suitable area and the several cover ejection methods operated. Measurements of force, acceleration, and trajectory recorded during these tests will complete the cover attachment and ejection subsystem test.

13.2.7.3 Equipment Required

A jig simulating the forward compartment, the forward bulkhead (station 82.75), the connecting tunnel, a heat shield and a simulated launch escape tower will be required. Fixtures will include a method for catching the heat shield without damage after ejection and to simulate airloads on the cover. Instrumentation for this test will include a high-speed motion picture camera synchronized with force and acceleration recording devices.

13.2.7.4 Facilities

S&ID facilities will be used.

13.2.8 Antenna Deployment and Steering Subsystem

13.2.8.1 Objectives

Determining the operational characteristics of the subsystem in its initial design configuration by test under simulated environmental and loading conditions will be the objective. Data obtained from these tests will be applied to improvement of the subsystem by revision or redesign. In particular, activities to be investigated include deployment operation, steering resolution and response, and shock loading at various attitudes.

13.2.8.2 Test Plan

Deployment and steering cycles will be run at various environmental and loading conditions to determine operational characteristics and control resolution and response. Shock loading tests will be run to determine feasibility of deployment under these conditions.

13.2.8.3 Equipment

A skeletal jig providing the attachment and pivot points of the subsystem mechanism and a structure simulating the actual contours and rigidity in the region of the antenna cavity will be required.

13.2.8.4 Facilities

S&ID facilities will be used.

14.0 MATERIALS, PROCESSES, AND PRODUCIBILITY

14.1 SCOPE

This section is intended to describe the planned approach to Apollo materials, processes, and producibility. It is probably impossible to anticipate all of the materials and producibility problems to be solved during the course of Apollo design and manufacturing. It is estimated that the tests and investigations will constitute only 35 to 50 percent of those that must ultimately be resolved.

The major criteria for design and material selection in the early spacecraft prototypes will be their successful airborne history. The materials research and process development work in support of this project will thus seek improvements and will be phased in at manufacturing or design change points after the process or material has been evaluated for producibility, reproducibility, and reliability under simulated prelaunch and space environmental conditions. The final proof of any material or process developed in support of this project will be its successful use on an unmanned spacecraft, prior to its firm incorporation into the design of a spacecraft intended for a manned mission.

14.2 S&ID TEST PLANS

14.2.1 Command Module Structure and Subsystem Installation

This constitutes a major portion of the Apollo materials and producibility effort. The command module structure and subsystems installation covers work on the structure, observation windows, the outer structural shell, the charring ablator, the inner structural shell, and the many items related thereto:

14.2.1.1 Objectives

The basic or primary objectives of the command module structure and subsystem installation are generally encompassed by the following:

1. Investigation of candidate materials properties from which the command module can be designed and fabricated. These materials are to be from commercially available stock, whenever possible

[redacted]

2. Selection of construction materials for the command module structure which meet functional requirements and established weight requirements or goals and which are capable of reliable function in the combined induced and natural hyperenvironments of space as encountered on a lunar mission

3. Testing and development of materials combinations, as required, when they are not available commercially, to achieve the most nearly optimum combination of reliability, economy, and producibility

4. Select and/or develop design criteria and fabrication methods which are required to produce a reliable subsystem capable of fulfilling all Apollo requirements within the required time period established by NASA

5. Define requirements of all materials required in the command module structure

14.2.1.2 Test Plan

The highlights of the test plan are presented in the following outline:

1. Conduct studies and necessary tests of applicable materials to determine properties, flammability and outgassing of toxic materials, and select candidate materials for each item required

2. Conduct additional tests, as required to establish mechanical and physical properties of candidate materials

3. Investigate the following items with respect to the inner shell of the command module:

   Candidate aluminum alloys

   Forming methods for materials

   Evaluate various methods and materials required to produce bonded aluminum honeycomb-type sandwich structural elements

   Determine the environments to which the inner command module shell materials will be subjected

   Subject specimens to simulated combined environmental conditions; if they are satisfactory, specify them; if they are unsatisfactory, continue developmental efforts until satisfactory results are achieved

4. Investigate requirements for openings in the inner shell and develop satisfactory methods for sealing provisions, etc., for these openings

5. Investigate, conduct necessary tests, and develop reliable methods for providing adequate lubrication for mechanical moving mechanisms (or movable mechanisms which are required as part of the command module)

6. Investigate, develop, and test, then specify as necessary, finishes for the command module inner shell and its components, including those required for a 100-percent oxygen atmosphere

7. Develop data and conduct necessary tests to describe optimum observation window materials, dimensions, processing, and coatings required for antireflectance and absorption of undesirable portions of the light spectrum, such as infrared and ultraviolet. Observation window materials must maintain an acceptable transmission level for the visible portion of the spectrum.

8. Conduct studies and evaluations as required to select materials from which the outer command module structural shell will be made. These include complete evaluations of such materials as aluminum alloys, titanium alloys, alloy steels, nickel base alloys, and cobalt base alloys

9. Conduct studies, evaluations, and tests to determine the best method to be utilized in fabricating outer command module structural shell honeycomb type sandwich components. These methods include adhesive bonding, diffusion bonding, welding (as with stresskin), and high temperature brazing

10. Conduct cryogenic, room, and elevated temperature tests to determine the important mechanical properties of such structural honeycomb type sandwiches as:

    Adhesive bonded aluminum alloy

    Diffusion bonded sandwich with 6Al-4V titanium alloy faces and commercially pure titanium core

    High temperature brazed PH14-8Mo alloy steel and welded stresskin

    Rene 41 high temperature brazed, nortobrazed, and stresskin

[redacted]

HS-25 cobalt base brazed superalloy sandwich

HS-25 cobalt base superalloy stresskin (all-welded sandwich)

11. Determine the cryogenic and elevated temperature properties of elastomeric materials required for command module fabrication

12. Determine the most reliable methods for attachment of the charring ablative material to the outer structural shell of the command module

13. Conduct tests and employ experimental methods required to form and fabricate command module components. These include fastening, welding, bonding with adhesives, brazing, soldering, diffusion bonding, etc. Select and specify the optimum method to be employed in each fabrication step or assembly sequence

14. Conduct tests required to determine the ability of command module materials assemblies and/or elements to withstand the total combined natural and induced environmental combinations.

14.2.1.3 Equipment

The equipment required to perform all of the tests required for the command module structure and subsystem installation project exists only partially. The majority of the basic equipment required exists within the NAA corporate organization and combined outside organizations. Relatively little new equipment will be mandatory, although considerable modification of existing equipment is anticipated. Also, existing equipment must be made available, when needed, if new equipment procurement is to be avoided.

14.2.1.4 Facilities

No new facilities will be required for the material and producibility portion of the command module structure and subsystem installation. It is expected that currently available facilities, both within and outside the company, are adequate to cover this project.

14.2.1.5 Test Schedule

The command module structure and subsystem installation covers a sufficiently wide variety of different task types that a specific schedule cannot be applied to it. Work on this was initiated almost as soon as the project Apollo was started and will probably continue until the project is terminated. Work on material, process, and producibility improvement will probably closely follow completion of work on the basic spacecraft.

[redacted]

14.2.2 Service Module Structure and Subsystem Installation

The materials and producibility group effort on the service module structure and subsystem installation consists of the selection of materials, establishment of acceptable manufacturing and processing techniques, and determination of design properties of the materials used.

14.2.2.1 Objectives

1. Evaluate materials for the service module structure and substructure. These should be from commercially available materials, where possible

2. Select materials which meet the design requirements of the functional requirements and are compatible with load requirements

3. Compare the materials and manufacturing techniques from the standpoint of cost, producibility, and reliability

14.2.2.2 Test Plan

1. Conduct a study of the service module structure and determine the most suited materials for the applications in the service module

2. Determine the mechanical properties, physical properties, availability, and producibility of the selected materials for each application

3. Determine the environments that each material will be subjected to during the lunar mission and perform tests to insure satisfactory functioning during the mission

14.2.2.3 Equipment

The equipment necessary for this program is available in S&ID and other NAA divisions. No new equipment should be necessary for this testing and evaluation.

14.2.2.4 Facilities

No new facilities will be required for this program. All necessary facilities are available within NAA.

[redacted]

[redacted]

14.2.2.5 Test Schedule

The service module structure and subsystem installation effort will continue until the end of the program. A continual evaluation for improvement will be required as changes and manufacturing progress occur; therefore, no definite test schedule can be established.

14.2.3 Service Module Propulsion Subsystem

The materials and producibility group is testing materials and evaluating manufacturing and processing techniques for the fuel and oxidizer tanks and the associated plumbing system.

14.2.3.1 Objectives

1. Evaluate materials for the fuel and oxidizer tanks and select the material best suited for mission accomplishment
2. Select manufacturing and processing techniques for providing the most reliable system
3. Evaluate materials and brazing processes for the plumbing system associated with the fuel and oxidizer system and establish the best materials, fabrication, and processing procedures for the system
4. Determine the relative producibility and cost criteria and reliability of the fuel, oxidizer, and associated plumbing system
5. Demonstrate compatibility between the system components and their contents

14.2.3.2 Test Plan

1. Determine the mechanical properties of the materials selected for the fuel and oxidizer tanks in the environments to be experienced during the lunar mission (i.e., temperature, oxidizer, fuel, etc.)
2. Determine the manufacturing and processing methods which produce the most reliable system under the environmental conditions
3. Conduct tests to determine the tubing materials and manufacturing processes best suited for the plumbing system
4. Compare the cost, difficulty of production, and reliability to determine the optimum materials and manufacturing methods for the system

14.2.3.3 Equipment

The equipment necessary for the testing and evaluation of the materials and processes for this program is existent at S&ID and NAA Divisional facilities.

14.2.3.4 Facilities

No new facilities will be required to test the materials or evaluate the manufacturing processes. All facilities necessary are available within NAA or outside the company.

14.2.3.5 Test Schedule

Work on this system is expected to continue until the program is practically completed. Continuous design changes and manufacturing difficulties which will occur in the Apollo program will necessitate constant effort and surveillance on this part of the program.

14.2.4 Reaction Control System

The role of Apollo materials and producibility in the reaction control system is the selection and evaluation of materials in the environment to which the system will be exposed. Both the base material and the protective coating will be evaluated.

14.2.4.1 Objectives

1. Evaluation of the physical and mechanical properties of the selected rocket nozzle materials and comparison with other possible applicable materials

2. Evaluation of the properties of the nozzle coating and comparison with possible alternate materials

3. Testing of the nozzle material and coatings in the simulator hyper-environment of space (i.e., temperature, meteoroids, etc.)

4. Select or develop alternate materials in the event of failure of the selected materials to meet the specified requirements

5. Establish the packaging and handling methods and procedures for the RCS nozzles

[redacted]

14.2.4.2 Test Plan

1. Determine the properties of the material presently selected for the nozzle. Compare this data with existent data on other possible materials

2. Determine the properties of the nozzle coating presently selected and compare this data with alternate possible candidates

3. Determine the functionality of the nozzle and the coating in the mission environment

4. Develop packaging and handling procedures for the nozzles to prevent damage during handling and shipping

14.2.4.3 Equipment

The equipment necessary for the testing and evaluation of the nozzle materials and coatings is available within North American Aviation. No new equipment will be necessary for this evaluation.

14.2.4.4 Facilities

The facilities at S&ID and NAA Divisional facilities are adequate to handle this testing program.

14.2.4.5 Test Schedule

The work in this portion of the program is scheduled to be completed by June 1964.

14.2.5 Launch Escape Subsystem

14.2.5.1 Objectives

The launch escape subsystem includes both subcontracted and contractor fabricated elements. Such subcontracted items as the solid propellant launch escape rocket are not considered in this portion of the test plan. Basically, this section covers the launch escape tower and S&ID-fabricated accessories. Because the launch escape tower is to be ejected or jettisoned in the early part of an Apollo mission, materials utilized in its construction must exhibit the highest degree of efficiency from the standpoint of weight versus strength. Since the entire launch escape system must be lifted from earth by the first-stage rockets, substantial advantage is to be gained from the use of highly efficient structural materials. The firing of the launch

escape rocket, either to separate the tower from the remainder of the system or to effect an escape, will result in sudden and severe heating of the structure. This will require protection for the structure. The general material and producibility objectives to be considered in connection with the launch escape subsystem are as follows:

1. Determine mechanical and physical properties of candidate materials from which the launch escape tower may be fabricated

2. Compare the properties of candidate materials and select those which are most nearly compatible with over-all requirements

3. Determine the relative producibility and cost criteria for candidate launch escape tower materials

4. Select the material combinations which most nearly fulfills all requirements for the Apollo spacecraft launch escape tower structure

5. Select the fabrication methods which appear most readily adaptable to launch escape tower fabrication

14.2.5.2 Test Plan

General elements of the launch escape subsystem test plan include, but are not necessarily limited to, the following items:

1. Obtain candidate launch escape tower materials and conduct mechanical and physical property tests to determine whether or not these materials are capable of meeting established requirements

2. Conduct necessary fabrication tests and evaluations to determine whether or not candidate materials can be readily converted from mill products into tubular products from which components can be readily fabricated

3. Investigate joining methods to be utilized in fabricating the launch escape tower and select such optimum methods of fabrication as TIG and MIG welding, electron beam welding, etc.

4. Determine the environmental conditions, such as temperature and vibration, which must be successfully withstood by launch escape subsystem components

[redacted]

5. Determine and apply methods of protecting launch escape subsystem structural components from the adverse effects of environmental extremes. Conduct tests required to demonstrate adequacy of such protective measures as thermal protective coatings, etc.

6. Demonstrate the ability of S&ID-fabricated launch escape subsystem components, by testing under simulated service conditions, to successfully withstand the total anticipated service environments and loads

14.2.5.3 Equipment

The equipment required for testing and evaluating the S&ID-fabricated portion of the launch escape subsystem is available either at S&ID or at other divisions of North American Aviation, Inc.

14.2.5.4 Facilities

Facilities for fabrication and testing of the S&ID-fabricated portion of the launch escape subsystem currently exist within the North American Aviation organization.

14.2.5.5 Test Schedule

Launch escape component and subsystem testing are scheduled for completion not later than 30 June 1963. Launch escape tower fabrication technique tests were completed on 21 December 1962.

14.2.6 Alternate Heat Shield

The purpose of this program is to select an alternate material for the heat shield material presently selected. The function of the materials and producibility group in this program is to evaluate the candidate materials and select one as the backup material.

14.2.6.1 Objectives

1. Evaluation of the physical, mechanical, and thermal properties of the candidate materials

2. Compare the properties of the various candidates and select the most likely materials, based on mission requirements for extensive testing

[redacted]

3. Test extensively the materials selected in Part (b) and compare the test data on these materials

4. Subject the candidate materials to the simulated space environment (i.e., ultraviolet radiation, particulate radiation, hard vacuum, etc.)

5. Select the material most suited as a backup material on the basis of properties and ability to withstand the environmental conditions

14.2.6.2 Test Plan

Phase I - Screening tests

1. Select candidate materials and prepare specification for each material

2. Fabricate the material and prepare test specimens for preliminary testing

3. Perform preliminary tests on mechanical and physical properties for screening the original materials selected

4. Perform preliminary environmental testing to screen the candidate materials

5. Select the most likely material from the original candidates for extensive testing

Phase II - Test program

1. Perform complete evaluation of the physical, mechanical, and thermodynamic properties of the candidate material selected in Phase I

2. Perform an evaluation of the behavior of the candidate material selected in Phase I in a simulated environment encountered on the lunar mission

3. Compile design allowables for Apollo space radiator and cold plate design on the back-up materials from the testing performed in Phase II

[redacted]

[redacted]

14.2.6.3 Equipment

The equipment necessary for the property testing of the candidate materials is available at NAA, S&ID and Divisional facilities. Some equipment may be necessary for the environmental evaluation of the candidate materials in Phase II.

14.2.6.4 Facilities

The facilities to be utilized in this program will include:

1. S&ID facilities
2. NAA Divisional facilities
3. Subcontractor facilities

14.2.6.5 Test Schedule

This program was completed in June 1963.

14.2.7 Environmental Control Subsystem

14.2.7.1 Objectives

The portion of the environmental control subsystem with which Apollo materials and producibility is concerned includes development of satisfactory fabrication techniques for space radiators and cold plates, selection and testing of temperature control coatings of the space radiator surfaces, and protection of these coatings from the time that they are applied to vehicle launch. The objectives of this task includes the following:

1. Selection of the most nearly optimum materials from which space radiators and cold plates are to be fabricated
2. Development of fabrication techniques for space radiator and cold plate fabrication
3. Determination of optical and physical requirements for temperature control surface coatings
4. Development and testing of temperature control coatings which fulfill basic system requirements
5. Determination of space environmental effects on space radiators and on temperature control surface coatings

[redacted]

14.2.7.2 Test Plan

The test plan includes the following specific items:

1. Based upon established system requirements, select the best available materials from which space radiators may be fabricated. Conduct tests, as necessary, to substantiate materials selection

2. Conduct necessary tests and experiments to determine optimum fabrication methods for space radiators. Conduct experiments required to prove that components fabricated by the method selected are capable of satisfactory operation in the space environment

3. Conduct screening tests to determine which of the available candidate temperature control surface coatings are capable of meeting minimum established optical and physical property requirements

4. Select candidate temperature control surface coatings meeting minimum requirements for additional tests

5. Subject candidate temperature control surface coatings to combined simulated service conditions, including ultraviolet temperature extremes, meteoroids, charged particle radiation, hard vacuum, etc., and select the coating(s) which best withstand simulated service environments

6. Modify and/or develop coating(s) as necessary to render them less vulnerable to environmental effects

7. Select the coating to be employed on the space vehicle and develop methods of protecting the temperature control surface from the time of coating deposition to the time of vehicle launch

14.2.7.3 Equipment

The equipment for work required in developing this portion of the temperature control system exists either at S&ID and other North American Aviation Divisions or at subcontractor facilities. It is expected that equipment modification may be required to permit application of temperature control coatings to relatively large panels required for the Apollo project.

14.2.7.4 Facilities

Existing S&ID and NAA divisional facilities are considered adequate for work required in this portion of the environmental control subsystem.

[redacted]

14.2.7.5 Test Schedule

All work included in this portion of the environmental control subsystem is scheduled for completion by 30 October 1964.

14.2.8 Communications Subsystem

The portion of the communications subsystem covered in this section of the test plan involves primarily evaluation of radome (telecommunication window) materials and miscellaneous items, such as cables, shielded wires, and connectors requiring materials evaluations.

14.2.8.1 Objectives

The objectives of this program involve the following:

1. Evaluation and studies of candidate materials and selection of those which should be seriously considered for Apollo communication subsystem application

2. Testing of candidate materials to determine whether or not they are capable of functioning satisfactorily under anticipated service conditions

3. Recommending communication subsystem materials for specific design applications on the Apollo vehicle after having determined environmental conditions under which related components must operate

14.2.8.2 Test Plan

The test plan for this portion of the communications subsystem is presented in the following items:

1. Determine the physical and mechanical properties of candidate materials which are considered in fabrication of:

   The discone antenna window (radome)

   Other radomes mounted on the command module exterior

   Cables, insulation, and various connectors which are utilized in both the command module exterior and interior

2. Conduct tests required to determine compatibility of candidate communication subsystem materials with a 100 percent oxygen environment

3. Conduct tests required to determine the single and combined effects of the space environment (charged particle radiation, hard vacuum, meteoroids, etc.) on specific candidate materials

4. Conduct the tests required to determine flammability of materials in a 100 percent oxygen atmosphere and tests to determine whether or not candidate materials emit undesirable fumes or gases

5. Conduct tests to provide mechanical property data on candidate ceramics (quartz, fused silica, alumina, beryllia, zirconia, etc.) for use as radome structures. Determine effects of simulated combined space environments on such materials

6. Determine electrical properties, as necessary, on candidate dielectrics

14.2.8.3 Equipment

The equipment required to evaluate and/or test communications subsystem materials is available at S&ID, at other NAA divisions, or at supplier facilities. No new equipment will be required for general materials testing.

14.2.8.4 Facilities

Facilities required for communication subsystem materials evaluation are considered to exist at one or more of the following facilities:

1. S&ID Laboratories
2. Other NAA Divisions
3. Material supplier facilities
4. Subcontractor facilities
5. Research and development organization facilities

14.2.8.5 Test Schedule

All testing of materials for prototype articles, as well as for production spacecraft items, are scheduled for completion not later than 30 December 1964.

[redacted]

14.2.9 Radiation Testing of Materials

14.2.9.1 Objectives

Certain materials employed in the fabrication of the Apollo spacecraft may be, according to current literature, adversely affected by the amounts of charged particle radiation to which they can be exposed during a normal Apollo mission. In other words, their threshold damage may be exceeded on an average Apollo mission. The objectives of this program include the following:

1. Identify the charged particle radiation environment

2. Determine the threshold damage or damage limits for the material being investigated

3. Determine which materials will have their threshold damage limits exceeded on an Apollo mission and by what extent these limits will be exceeded

4. All materials that have threshold damage limits that may be exceeded on an Apollo mission will be subjected to simulated radiation environments (energies and quantities) which they will experience on an Apollo lunar mission. The damage caused by charged particle radiation during a mission will be determined

5. Pre-irradiation and post-irradiation tests will be required to show how much and what type of radiation damage has been sustained by each susceptible material

6. Based upon test results, a recommendation will be made either recommending use of or discontinuing use of each material susceptible to radiation damage.

14.2.9.2 Test Plan

The test plan consists essentially of the following items:

Basic Tests

1. Radiation screening tests on candidate alternate heat shield charring ablators.

[redacted]

2. Simulated charged particle space radiation doses to 31-mev protons of the following doses: 10^{11}, 10^{12}, 10^{13}, and 10^{14} protons per square centimeter.

3. Conduct pre-irradiation and post-irradiation tests necessary to determine the amount and type of radiation-induced damage caused by charged particle radiation exposures.

Long Range Tests

1. Long range tests may involve Teflon, Buna N rubber, silicone rubber, butyl rubber, ethylene glycol, aluminosilicate glass (observation window material), fused silica (heat shield window material), temperature control surface coatings, and other critical materials that may be susceptible to charged particle radiation damage.

2. Each material will be exposed to the charged particle radiation level (as nearly as possible) which it is likely to sustain on an Apollo mission. The types of radiation to which a typical surface material is likely to be exposed on an Apollo mission include gammas, 2 to 10-mev electrons, and protons of the following energies: 30 mev, 50 mev, 70 mev, 100 mev, and 160 mev.

3. All radiation exposures will be made while the specimens are in a 10^{-6} mm Hg vacuum or better.

4. Pre-irradiation and post-irradiation testing of specimens will be conducted before and after charged particle radiation exposures to determine if damage is caused by charged particle radiation.

5. Each series of materials tests and test results will be examined analytically to determine potential charged particle radiation effects on the over-all Apollo materials behavior.

6. Analytical work will also be conducted in an attempt to develop a method for accurately predicting space-type charged particle radiation effects on materials, based upon test data developed in reactor or similar type tests.

14.2.9.3 Equipment

The equipment required includes the following:

1. Scattering chamber assembly for holding test specimens in a vacuum during exposure to the charged particle beam

2. Miscellaneous minor optical measuring equipment for determining damage to temperature control coatings caused by charged particle radiation

3. Miscellaneous chemical-type equipment required for handling fluid materials while they are being irradiated

4. Beam time on electron and/or proton accelerators for exposure of specimens. This includes only beam time or use of charged particle accelerating equipment, not equipment purchase.

14.2.9.4 Facilities

No new facilities are needed. The use of existing accelerator site facilities will suffice. Existing NAA facilities will be adequate for anticipated preirradiation and postirradiation tests.

14.2.9.5 Test Schedule

This test was completed in June 1963.

Long range tests are expected to require approximately one year from initiation of testing, provided that accelerator beam time can be obtained as easily as now appears possible. All charged particle radiation tests should be complete by 30 December 1964.

14.2.10 Structural Leak Detection

14.2.10.1 Objectives:

The maximum total leak rate for the Apollo cabin has been established as 0.2 pounds of oxygen per hour at differential pressure (this is equal to 1.8×10^{-1} cc of oxygen per second). To achieve this maximum leak rate, the following program objectives have been set:

1. Identify the welded joints where leakage can occur

2. Identify the rubber or elastomer sealed joints that may be subject to leakage

3. Determine practical leak detection methods that are sufficiently accurate to measure the total leakage taking place in a given area

4. Determine a practical method for measuring the total Apollo command module leakage, both prior to and subsequent to final assembly

5. Determine practical and accurate methods for checking handling damage, post-weld cracking, and weld repairs with respect to leakage

6. Prepare a process specification covering all significant facets of cabin leakage criteria.

14.2.10.2 Test Plan:

The following constitute the basic test plan for structural leak detection:

1. Investigate such methods as a vacuum cup using water and helium mass spectrometer methods for measuring leakage in weld areas and in rubber sealed areas, such as doors and windows

2. Select optimum methods for measuring the leakage rate at each type of site where leakage is likely to be encountered

3. Measure weld leakage prior to final assembly, using the optimum methods developed

4. Measure leakage caused by handling damage and post-weld cracking (if any), and check repaired areas for leaks

5. Measure leakage at the proper predetermined assembly events, such as the command module half-shell face sheets both before and after assembly into major subassemblies and final assembly.

14.2.10.3 Equipment

The equipment needed for all phases of this task has not yet been completely catalogued, but the following is a listing of the basic equipment that will be required:

1. A helium mass spectrometer with modifications

2. Bubble check range equipment, including a vacuum cup using water

[redacted]

3. Specially designed and constructed or modified equipment based upon items 1 and 2 as required to permit checking of structural components that are peculiar to the Apollo command module.

14.2.10.4 Facilities

The requirement for new facilities is not anticipated. Existing NAA corporate facilities are now considered adequate for this task.

14.2.10.5 Test Schedule

This program encompasses a large number of different tasks, preventing application of effective scheduling. Development of leak detection and measurement techniques may be completed as soon as August 1964, but leak detection and measurement will continue throughout the entire spacecraft production period.

14.2.11 Apollo Contamination Control

Apollo systems, including fuel systems, coolant systems, etc., will be assembled from both NAA and subcontractor produced components. Maintaining an adequate level of cleanliness within these systems components as well as within the total assembled systems is absolutely imperative. This program is of utmost importance to successful spacecraft missions.

14.2.11.1 Objectives

The objectives of the contamination control program are as follows:

1. Establish cleanliness requirements that will be mandatory for the reliable function of each system

2. Provide materials, process, and producibility criteria to ensure that cleanliness requirements for the hardware are met and maintained, as well as being specified on applicable drawings

3. Determine specific system tolerance to particulate matter size and contamination level

4. Originate practical test methods for determining whether or not cleanliness requirements have been met by NAA and the subcontractors on the component, subassembly, and completely assembled systems levels

5. Investigate post-assembly contamination sources or causes, such as corrosion, vibration, micro-organisms, etc., and originate methods for salvage of contaminated components and/or systems

6. Educate suppliers, subcontractors, and NAA personnel to maintain adequate cleanliness standards during fabrication so that produced systems are free from objectionable contaminants.

14.2.11.2 Test Plan

The following constitute the basic test plan for the control of contamination:

1. Conduct investigations and tests of applicable system components required to establish cleanliness requirements

2. Prepare applicable specifications in which both general and specific cleanliness requirements are clearly stated

3. Conduct investigations required to determine sources of contamination and/or contaminants that cannot be tolerated. This includes investigation of fittings, filters, construction materials, and compatibility between systems and their intended contents

4. Investigate, study, and specify methods or means for eliminating contamination of systems and/or systems components, plus establish clean room requirements for component manufacture and system assembly

5. Determine the tests that will be conducted to ascertain if cleanliness requirements are met. Specify the events at which cleanliness tests are to be conducted. Conduct the tests as specified.

6. Determine the methods by which system components that have failed to meet cleanliness requirements can be salvaged. These methods may include flushing with solvents, ultrasonic cleaning, a combinations of these, etc.

7. Determine and specify methods for maintaining cleanliness of the components once they are determined to be clean. This includes component and subsystem storage, and post system installation cleanliness.

14.2.11.3 Equipment

The equipment necessary for this program is available within S&ID, other NAA divisions, or at outside facilities. Very little, if any, new equipment should be required for this program. Some equipment modification may be required.

[redacted]

14.2.11.4 Facilities

No new facilities are foreseen as a requirement for this program. All necessary facilities appear to be available either within NAA or at subcontractor facilities.

14.2.11.5 Test Schedule

This program is expected to be continuous throughout the Apollo project. At this time, no test schedule can be established with any degree of accuracy.

[redacted]

15.0 WIND TUNNEL TEST PROGRAM

15.1 SCOPE

The scheduled wind tunnel test program will supply data on aerodynamic and rocket heating; stability during abort, entry and recovery; effects of center-of-gravity offset and heat shield ablation; interaction between separating bodies during escape operations; aerodynamic loads throughout the flight regime; and other problems that must be solved for the successful design of the Apollo.

A highly concentrated wind tunnel program is required to meet the internal release dates. This program will provide the necessary experimental data for the evaluation of the design and, wherever possible, will use large models for testing at Reynolds numbers approaching flight conditions. Detail design data will be generated, and detail design problems will be investigated, including tests of the Apollo recovery system and tests to assure compatibility between the command module and the other booster components.

15.2 TEST OBJECTIVES

The basic test objectives of the wind tunnel program are to provide, in the shortest possible time, sufficiently accurate and inclusive data to evaluate factors that affect the final design of the spacecraft, and to provide information to prove the validity of the configuration selected for final development.

15.2.1 Static Force Tests

Much of the initial testing to determine basic static stability and force characteristics of the entry and launch escape configuration throughout the flight regimes has been completed, using the FS-1, FS-2, FS-3, FS-4, and FS-8 models (For model definitions, see Section 15.4).

During transonic and supersonic tests of the FS-2 model, the individual loads acting on the escape motor and command module components of the launch escape vehicle were measured.

[redacted]

[redacted]

Tests have been conducted in the subsonic, transonic, and supersonic Mach number ranges on the FS-1, FS-2, and FS-3 models to investigate various devices on the command module to eliminate the apex-forward trim point.

Tests to determine the stability characteristics for any further modification to the command module or launch escape vehicle will be conducted on the FS-2 and FS-3 models.

Static stability characteristics of the launch escape vehicle with the escape motor operating have been determined using the FSJ-1 model with hydrogen peroxide as a propellant, and the FSJ-3 model with unheated air as the propellant.

The static stability and force characteristics of the Saturn 1 with detachable stages and the Apollo payload have been determined over the Mach number range from 0.7 to 8.0 with the FSL-1 model. This model has furnished aerodynamic data for launch vehicle abort trajectory studies.

Free-flight characteristics of the command module and launch escape vehicle, including static and dynamic stability data, are being investigated in ballistic range facilities.

Tests of the drogue chute models FSC-1 and FDC-1 have yielded drogue inflation and stability characteristics and drag data. Various parachute diameters and porosities have been tested to verify the configuration selected for the recovery system.

15.2.2 Dynamic Force Tests

Dynamic stability characteristics of the command module and launch escape vehicle have been obtained in limited Mach number and angle-of-attack ranges using the FD-1 and FD-2 models. Additional tests of FD-2 obtained the dynamic stability characteristics for modifications of the launch escape vehicle configuration. Dynamic stability data have been obtained on the command module at angles of attack from -10 to +190 degrees in the Mach number range from 1.5 to 10 and on the launch escape vehicle at angles of attack from -5 to +25 degrees in the Mach number range from 1.5 to 6.0 using the FD-3 model. Subsonic dynamic stability characteristics of the command module and launch escape vehicle have been obtained using the FD-4 model.

High-amplitude free oscillation tests have been conducted for the entry configuration (FD-5 model) at angles of attack corresponding to the heat shield and apex forward trim points in the Mach number range of 0.6 to 6.0.

[redacted]

Using the same model, data were obtained for the launch escape vehicle at its trim angle of attack over a Mach number range 0.6 to 4.0. Tests to obtain the tumbling dynamic stability characteristics of the command module were run with various stabilizing devices at a Mach number of 0.2, using the FD-8 model. Additional tumbling dynamic stability tests of the command module and launch tower vehicle will be conducted, during December 1963, using the FD-6 model. The test Mach number range will be 0.3 to 0.9.

Dynamic stability characteristics of the command module with the drogue chute have been obtained using the FDC-1 model. Parachute deployment characteristics with the command module at normal and apex forward trim also have been investigated.

15.2.3 Structural Dynamic Tests

The SD-1 model tests investigated the structural response of the Saturn-Apollo 1 launch configuration to buffeting loads in the transonic flight range. Measurements of aerodynamic damping have also been obtained from these tests.

15.2.4 Static Pressure Tests

Initial structural design loads were obtained for the command module and the launch escape vehicle from pressure measurements made on the PS-1 model in the Mach number range from 1.5 to 9.0. These data have been augmented with more complete pressure measurements on the PS-3 model in the Mach number range from 0.4 to 10. Pressure measurements have been obtained on the command module at Mach number 19.5 using the PS-4 model.

Tests have been conducted to obtain additional data on pressure loads for the launch escape vehicle with jet effects in the transonic range using the FSJ-1 model and in the supersonic range using the FSJ-3 model.

Pressure data with real gas effects have been obtained with the PS-5 model in the Mach number 15 region.

15.2.5 Static and Transient Pressure Tests

Static and transient pressure measurements have been made on the Apollo-Saturn 1 launch configuration in the Mach number range from 0.7 to 3.5 using the PSTL-1 model.

Additional tests to obtain the same information on the Apollo-Saturn 1B and V configurations have been scheduled that will use the PSTL-2 models.

[redacted]

15.2.6 Heat Transfer Tests

Initial heat transfer distributions were obtained for the command module and the launch escape vehicle from heat transfer measurements made on the H-1 model at Mach numbers 6, 7.3, and 9 in the JPL 21-inch hypersonic tunnel. These data have been augmented with more complete heat transfer measurements made on the H-2 model at Mach numbers 8 and 10, with higher Reynolds number simulation in tunnels B and C of the Von Karman Facility (VKF) at the Arnold Engineering Development Center (AEDC). Data have also been obtained at Mach 10 in the VKF tunnel C on the HL-1 and HL-1B launch configurations which incorporated the forward portion of the Saturn S-IV and S-IVB stages. Mach 19 heat transfer data were obtained over the command module entry face in the AEDC VKF tunnel F hot shot facility. Heat transfer tests were completed in the Cornell Aeronautical Laboratory's 48-inch shock tunnel on the entry configuration through the Mach number range 6 to 17.

The H-1 command module model and the H-9 sphere model were tested at Mach 10 in the AEDC VKF tunnel C to compare the heating rates on the face of the command module to those on a sphere of equal radius. A test was conducted in the Langley unitary plan wind tunnel on the entry configuration and the HL-1 launch configuration in the Mach number range from 2.5 to 3.7 to determine the effect of the strakes on the heating distribution. Additional information on the effects of the strakes, as well as the effects of the new launch escape tower configuration, was obtained in the AEDC VKF tunnel C at Mach 10.

Tests to obtain real gas effects on the heat transfer data over the entry face of the command module will be conducted in ballistic ranges and in plasma jet tunnels on the H-12 model. Plasma jet facilities, which are in the development stages, are currently being evaluated to select a suitable tunnel.

Two tests are planned for the immediate future. A heat transfer test in the LAD 12-inch shock tunnel will be run at Mach number 10 to 12 to determine leeward afterbody heating rates. The models will be wire-mounted to eliminate sting support effects.

Cornell Aeronautical Laboratory is constructing an 8-foot shock tunnel in which a 2- to 4-foot Apollo model can be tested to obtain heating for RCS apertures, windows, and protuberances. Instrumentation concentration in areas of special interest also may be achieved. Testing will be contingent on the completion and check-out of the shock tunnel.

[redacted]

15.3 TEST PROGRAM

The wind tunnel test program is divided into four phases to provide information for a man-rated spacecraft:

1. Preliminary design data uses idealized aerodynamic configurations for models.

2. Design confirmation models are updated to include effects of small asymmetries and surface irregularities that have been included in the vehicle design.

3. Production configuration evaluation models are updated to include the final production vehicle design.

4. Flight test support and modifications tests are specifically redesigned to support flight tests (e.g. boilerplate) or to evaluate recommended modifications as a result of flight test data.

The lower ranges of velocity and altitude encountered by the Apollo vehicle will be investigated by means of well-established wind tunnel techniques. Entry into the atmosphere will engender conditions that require new techniques. Several types of facilities must be used to obtain specific data for which each is best suited. In shock or hot-shot tunnels, for example, static stability and control effectiveness will be determined by use of very light-in-weight models mounted on internal strain-gage balances. In free-flight wind tunnels the trajectory of the model will be recorded by a series of shadow-graphs and analyzed to yield the required force data and dynamic coefficients. Dynamic stability is best evaluated in conventional supersonic wind tunnels by means of a dynamic balance. The model is forced to oscillate about a set angle of attack, and damping derivatives are determined from analysis of data with and without air flow over the model. Free damped oscillation techniques will also be used to determine damping derivatives.

Aerodynamic heating rates will be determined from output measurements of thin-film or variable reluctance heat transfer gauges, or from the temperature-time histories of thermocouples mounted on the inner surface of a thin-walled model. Data will be obtained from models tested in both shock tunnels and continuous flow tunnels. In free-flight wind tunnels, heating measurements will be made either by determination of the output of a single thermocouple, inductively, or by use of a miniature FM telemeter transmitter.

Radiative heating will be measured in the free-flight wind tunnel by means of a photomultiplier pickup in combination with a series of

[redacted]

monochromators. This instrumentation yields the energy wave length distribution of the glowing gas cap ahead of the model.

Heat transfer to the inside of the command module RCS nozzles from external flow has been simulated in a Mach 3 blowdown tunnel at the NAA-Los Angeles division.

15.4 EQUIPMENT REQUIREMENTS (MODELS)

The following models are required for testing to obtain the necessary data for the Apollo program. Figure 15-1 shows the following principal Apollo test configurations: launch configuration, launch escape vehicle, command module, and command module with service module.

15.4.1 Static Force (FS) Models

FS-1 A 0.02-scale model of the command module with serveral detachable escape tower configurations incorporating provisions for simulation of jet plume from escape motor.

FS-2 A 0.105-scale model of the command module with several detachable escape tower configurations. The large scale of this model will provide high Reynolds number data.

FS-3 A 0.045-scale model of the command module with detachable escape tower configuration. This model is designed for high-temperature flow.

FS-4 A lightweight 0.04-scale model of the command module for testing in impulse tunnels.

FS-6 A 0.013-scale model of the command module for testing in high-enthalpy flow in the entry attitude. This model will be fabricated and tested by NASA Ames Research Center.

FS-7 A 0.02-scale model of the command module with a parametrically varied shape.

FS-8 A lightweight 0.05-scale model of the command module for testing in impulse tunnels.

FS-9 A 0.105-scale model of the command module with apex drogue chute cover removed.

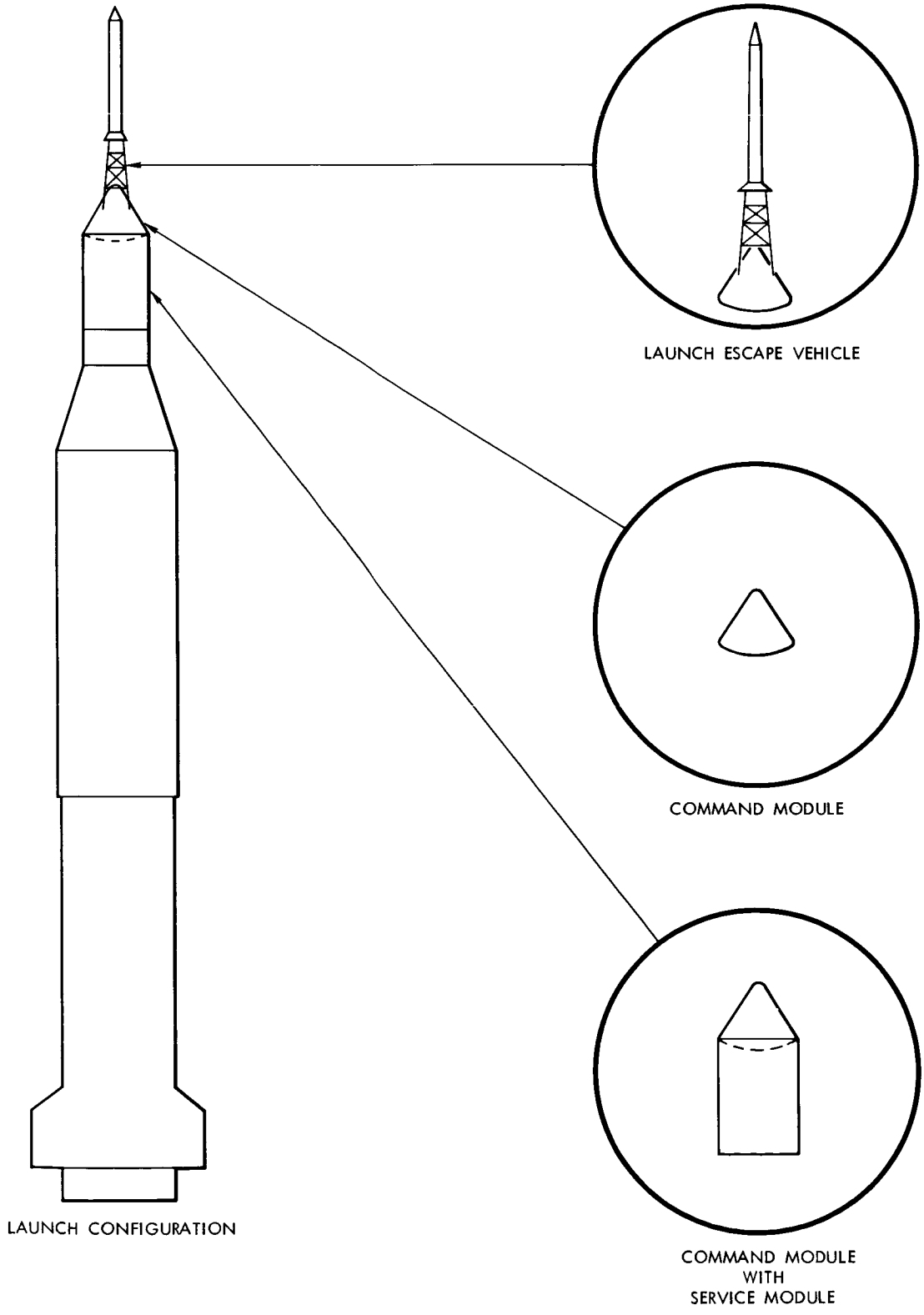

Figure 15-1. Apollo Test Configurations

FSC-1 A 0.10-scale drogue chute model with fixed command module. Three parachute diameters with various porosities and various riser elasticities will be tested. The models will include a drag balance for measuring the drag force of the chute.

FDC-1 A 0.10-scale dynamically similar command module with the drogue chute. The command module will be mounted for three degrees of freedom. The drogue chute diameter, porosity, and riser length and elasticity will be determined from the FSC-1 tests.

FSJ-1 A 0.085-scale H_2O_2 hot jet model of the launch escape vehicle that will be used to determine the effects of the launch escape motor exhaust plumes on LEV forces, pressures, and static stability in the transonic Mach number range.

FSJ-3 A 0.045-scale cold air flow model of the launch escape vehicle that will be used to determine the effects of the launch escape motor exhaust plumes on LEV forces, pressures and static stability in the supersonic Mach number range.

FSL-1 A 0.02-scale model of the complete launch (L) configuration with the Saturn I launch vehicle. Provisions for detaching the escape tower, the command module, and the service module will be provided to obtain the characteristics of the booster alone.

Ringsale No. 1 Full, one-half, and one-third scale models of the 1543-501 main Apollo parachute. Solid parachutes having hemispherical, flat, and conical gore shapes (all approximately 28 feet in diameter) were also tested.

Ringsail No. 2 One-third scale models of modified 1543-501 ringsail parachutes. The modifications will be determined from the results of the ringsail No. 1 test.

15.4.2 Dynamic Force (FD) Models

FD-1 Two 0.03-scale models of the command module, one with the center of gravity on the center line and the other with an offset center of gravity. Models will be of lightweight construction and will be mounted on air bearings.

FD-2 A 0.055-scale model of the command module with a detachable escape tower. Model is of lightweight and relatively simple construction to permit early testing.

FD-3 A 0.045-scale model of the command module with a detachable escape tower.

FD-4 A 0.10-scale model of the command module with a detachable escape tower. This model is being fabricated and tested by the NASA Langley Research Center.

[redacted]

FD-5 A 0.05-scale model of the command module and a 0.059-scale model of the launch escape vehicle. Models are of lightweight construction to be mounted on gas and ball bearings.

FD-6 0.10-scale dynamic models of the command module and launch escape vehicle will be used for tumbling dynamic tests. Models will be of lightweight construction and will be mounted on gas and ball bearings.

FD-8 The 0.10-scale modified FDC-1 model for use during tumbling dynamic tests. The model is of lightweight construction and is mounted on a ball bearing.

15.4.3 Structural Dynamic (SD) Models

SD-1 A 0.08-scale model of the SA-5 launch configuration. The model is flexible with scale stiffness distribution and variable mass distribution for simulating the correct mass at Mach numbers 0.8, 1.0, and 1.2. The model is spring-mounted to allow bending in the first and second free-free bending modes, as well as pitch oscillation about the center of gravity. Instrumentation includes bending moment strain gauges, accelerometers, and transducers for measuring transient pressures. An electromagnetic shaker installed between the sting and model is used to excite the model to obtain aerodynamic damping in pitch.

15.4.4 Static Pressure (PS) Models

PS-1 A 0.02-scale model of the command module with detachable escape tower configurations. This model is instrumented with pressure taps for obtaining pressure distributions on the command module with and without the escape tower installed.

PS-3 A 0.045-scale model of the command module with detachable service module and escape tower configurations. This model is instrumented with pressure taps for obtaining pressure distributions on the escape motor, command module, and service module.

PS-4 A 0.04-scale model of the command module. This model is instrumented with miniature pressure transducers to obtain pressure distributions in impulse tunnels.

[redacted]

[redacted]

PS-5 A 0.05-scale model of the command module instrumented with miniature pressure transducers to obtain pressure distributions in impulse tunnels.

PS-6 A 0.01875-scale model of the command module instrumented with miniature pressure transducers to obtain pressure distributions in impulse tunnels.

PS-7 A 0.125-scale model of the command module instrumented with miniature pressure transducers to obtain pressure distributions in impulse tunnels.

15.4.5 Static and Transient Pressure (PST) Models

PSTL-1 A 0.055-scale model of the launch (L) configuration with only the forward portion of the Saturn 1 launch vehicle duplicated. This model has provisions for detaching the escape tower. This model is instrumented with static pressure taps and acoustical pickups to obtain static and transient pressure distributions on the command module, the service module, and the Saturn-IV.

PSTL-2 This model will simulate the Saturn 1B and IV launch configurations. All windows and protuberances are included on this model. The instrumentation consists of static and transient pressure taps for obtaining pressure distributions over the forward portion of the launch vehicle and spacecraft.

15.4.6 Heat Transfer (H) Models

H-1 A thin-skin 0.02-scale model of the command module, and command module plus service module launch escape vehicle, instrumented with thermocouples to obtain heat transfer rates. The service module also is instrumented with pressure taps.

H-2 0.045-scale models of the command module, launch escape system, and service module. These models are constructed with thin skins and are instrumented with thermocouples to obtain heat transfer rates.

H-4 A 0.05-scale model of the command module for testing in impulse tunnels. This model was instrumented with thin-film resistance thermometers to obtain heat transfer rates.

[redacted]

[redacted]

H-6 A 0.01875-scale model of the command module instrumented with thin-film platinum resistant heat transfer gauges for obtaining heat transfer rates.

H-7 A 0.040-scale thick-skin, stainless steel model of the command module instrumented with thin wafer calorimeters and tested in hot-shot tunnels.

H-9 A thin-skin, stainless steel sphere having the same diameter as the entry face of the H-1 model and instrumented with thermocouples.

H-11 0.20-scale model of the actual flight configuration instrumented with thin-film platinum heat transfer gages. This model will be used to obtain heat transfer distributions in the vicinity of holes, windows, and protuberances. The model will be tested in an impulse tunnel.

H-12 Deleted.

H-14 Deleted.

HBR-1 A 0.45-inch diameter model of the command module for testing in a ballistic range facility. Approximately fifteen of these models will be required. These models will be fabricated and tested by the Ames Research Center.

HL-1 A 0.045-scale model of the launch configuration with only the forward portion of the Saturn 1 launch vehicle duplicated. This model will be constructed with a thin skin and will be instrumented with thermocouples to obtain heat transfer rates. This model is made with some modified parts of the H-2. These parts are interchangeable with the original H-2 configuration.

HL-1B A modification of the Saturn booster flare angle on the HL-1 model from 13 to 25 degrees to simulate the S-IVB stage.

[redacted]

HM-1 0.040-scale model of the Mercury entry configuration to determine the validity of afterbody heat transfer measurement in the LAD 12-inch shock tunnel. The model will be made of wood and will be instrumented with thin-film resistance gages.

15.5 TEST FACILITIES

The Apollo wind tunnel test program has taken into account the wide range of flight conditions that the spacecraft will encounter from launch to entry and recovery. To obtain data applicable to these conditions, many types of facilities will be used. These facilities are listed with a brief description of their characteristics. The capability of these facilities to simulate the Apollo boost and entry trajectories is graphically presented in Figures 15-2 and 15-3.

15.5.1 Continuous Tunnels

North American Aerodynamics Laboratory – 7.75-by 11-foot low-speed wind tunnel. A Mach number of approximately 0.2 can be obtained at a Reynolds number of approximately 1.44×10^6 per foot.

North American Columbus Division Aerodynamics Laboratory – 7- by 10-foot subsonic wind tunnel. A Mach number range from 0.05 to 0.39 can be obtained at a Reynolds number of approximately 2.7×10^6 per foot.

Langley – 20-foot free-spinning tunnel. A velocity of 0 to 66 mph can be obtained at a Reynolds number range from 0 to 0.62×10^6 per foot.

Langley – 12-foot low-speed tunnel. A velocity of 40 to 50 mph is obtainable in this tunnel.

Langley – 8-foot transonic pressure tunnel. Mach numbers from 0 to 1.2 are available over a Reynolds number range from 1 to 4 $\times 10^6$ per foot.

Langley – unitary plan wind tunnel. Two 4- by 4-foot test sections are used. One covers Mach numbers from 1.5 to 2.8, and the other Mach numbers from 2.6 to 5 at Reynolds numbers up to 10×10^6 per foot.

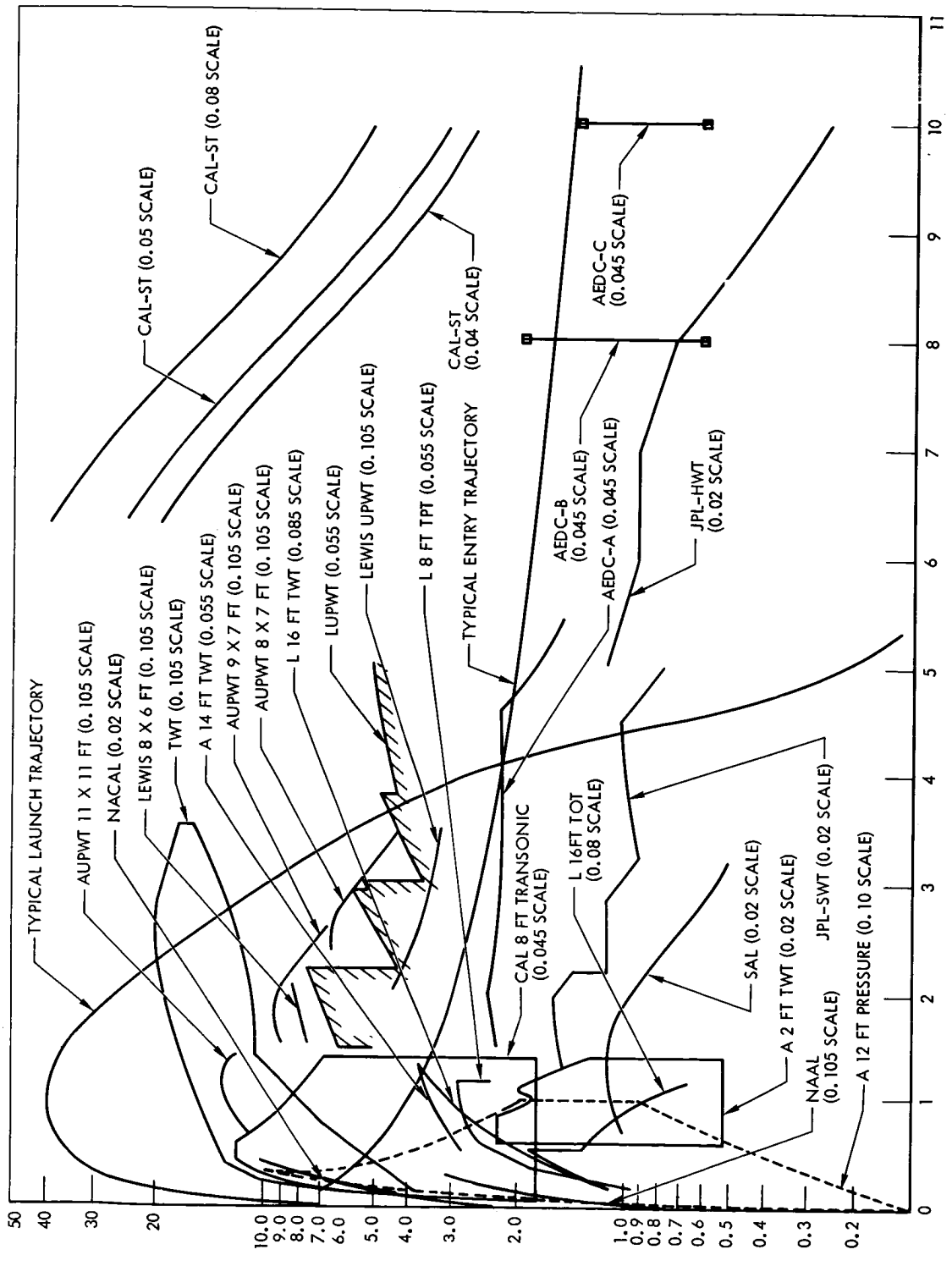

Figure 15-2. Test Facilities Capabilities (Reynolds Number Versus Mach Number)

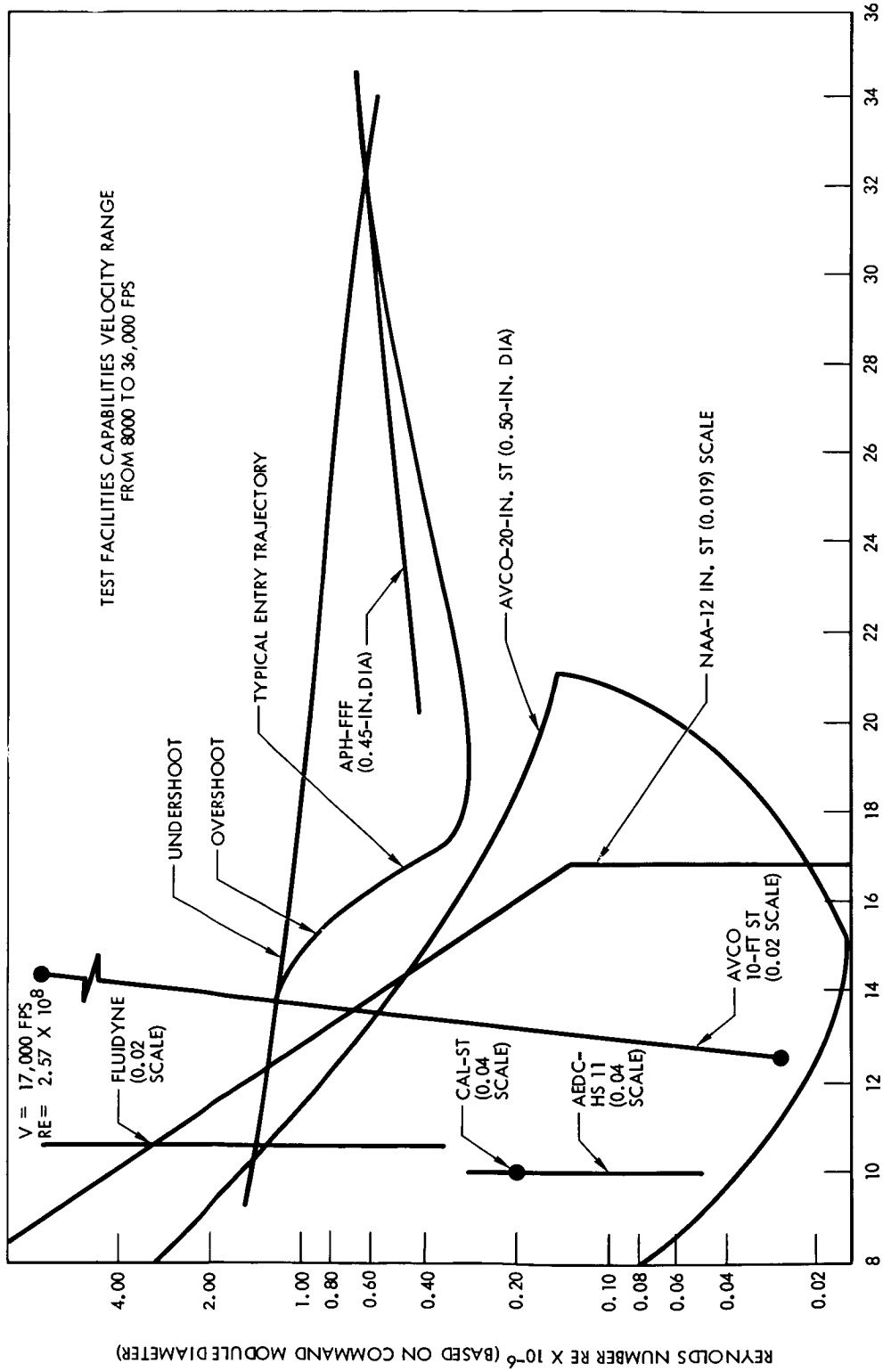

Figure 15-3. Test Facilities Capabilities (Reynolds Number Versus Velocity)

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Langley – 16-foot transonic dynamics tunnel. Mach numbers from 0.3 to 1.2 can be obtained. Reynolds number varies from 0.04×10^6 to 9×10^6 per foot. The tunnel may be operated using either air or freon as the test media.

Langley – 16-foot transonic wind tunnel. Mach numbers from 0.2 to 1.3 can be obtained. Reynolds number varies from 1.2×10^6 to 4.15×10^6 per foot.

Jet Propulsion Laboratory – 20-inch supersonic wind tunnel. Mach numbers from 1.3 through 5 can be achieved, and Reynolds numbers between 0.4×10^6 and 6×10^6 per foot are obtained.

Jet Propulsion Laboratory – 21-inch hypersonic wind tunnel. This facility covers the Mach number range between 5 and 9.5 at Reynolds numbers from 0.25×10^6 to 3.6×10^6 per foot.

Arnold Engineering Development Center Von Karman Facility – 40-inch tunnel A. Mach numbers from 1.5 to 6 can be obtained, and a Reynolds number range from 0.3×10^6 to 9×10^6 per foot can be covered.

Arnold Engineering Development Center Von Karman Facility – 50-inch tunnel B. This tunnel operates at Mach number 8 over a Reynolds number range from 0.25×10^6 to 3.3×10^6 per foot.

Arnold Engineering Development Center Von Karman Facility – 50-inch tunnel C. A Mach number of 10 is obtained with a Reynolds number range from 0.29×10^6 to 2.5×10^6 per foot.

Ames – unitary plan wind tunnel. This facility has three test sections. The 11-foot test section covers the range from Mach number 0.7 to 1.4 at Reynolds numbers up to 8.5×10^6 per foot. The 9- by 7-foot test section operates between Mach number 1.5 and 2.6 at Reynolds numbers up to approximately 6×10^6. The 8- by 7-foot test section covers a Mach number range from 2.4 to 3.5 at Reynolds numbers up to the order of 3 to 5×10^6 per foot.

Ames – 14-foot transonic wind tunnel. This tunnel operates at Mach numbers from 0.6 to 1.2 at Reynolds numbers from 2.8×10^6 to 4.2×10^6 per foot.

Ames – 2-foot transonic wind tunnel. This tunnel operates at Mach numbers from 0 to 1.4 at Reynolds numbers from 2×10^6 to 8.4×10^6 per foot.

[redacted]

[redacted]

Ames – 6-inch arc jet tunnel. This tunnel operates at Mach numbers 10 and 16 with a stagnation enthalpy of 900 Btu/lb.

Ames – 12-foot pressure wind tunnel. This tunnel operates at Mach numbers 0 to 1.0 at Reynolds numbers from 0 to 9.2×10^6 per foot.

Ames – 7 by 10-foot low-speed tunnel. Velocities of 0 to 300 mph are obtainable in this tunnel.

Ames — 40 by 80-foot low-speed continuous tunnel. This tunnel operates at velocities from 0 to 200 knots at Reynolds numbers from 0 to 2.1×10^6 per foot.

15.5.2 Intermittent Tunnels

North American Aviation – Supersonic Aerophysics Laboratory. Mach numbers of 0.7 and from 1.56 through 3.75 and Reynolds numbers between 3.88×10^6 and 2.26×10^6 per foot are obtained in this tunnel.

North American Aviation – 7 by 7-foot trisonic wind tunnel. Mach numbers from 0.2 to 3.5 are available, and Reynolds numbers from 5×10^6 to 14×10^6 per foot can be obtained.

Fluidyne – 20-inch Mach number 14 hypersonic tunnel. Reynolds numbers from 0.028×10^6 to 0.6×10^6 per foot can be obtained.

15.5.3 Impulse Tunnels

Arnold Engineering Development Center Von Karman Facility – 100-inch tunnel F and 50-inch hot-shot II. These tunnels currently operate with nitrogen as a test medium at Mach numbers from 16 to 21. Stagnation pressure is normally 1000 atmospheres.

Avco – 20-inch shock tunnel Mach numbers from 8 to 28 can be obtained with a Reynolds number range from 10^3 to 1.2×10^5 per foot.

Cornell Aeronautical Laboratory – 24- and 48-inch shock tunnels. Mach numbers from 5 to 18 can be obtained with a Reynolds number range from 0.03×10^6 to 10×10^6 per foot at the lower Mach number.

Cornell Aeronautical Laboratory – 6-foot shock tunnel. Mach numbers from 10 to 30 are available, and a Reynolds number range from 2×10^2 to 5×10^5 per foot can be obtained.

North American Aviation – 12-inch shock tunnel. Mach numbers from 7 to 22 can be obtained with a Reynolds number range from 0.0001×10^6 to 5×10^6 per foot.

[redacted]

15.5.4 Free-Flight Facilities

Ames Prototype Hypersonic Free-Flight Facility. Velocities up to 40,000 fps are obtained by firing models approximately 0.45 inches in diameter into a hypersonic shock tunnel.

15.6 TEST SCHEDULES

The wind tunnel test schedule is shown in Figure 15-4.

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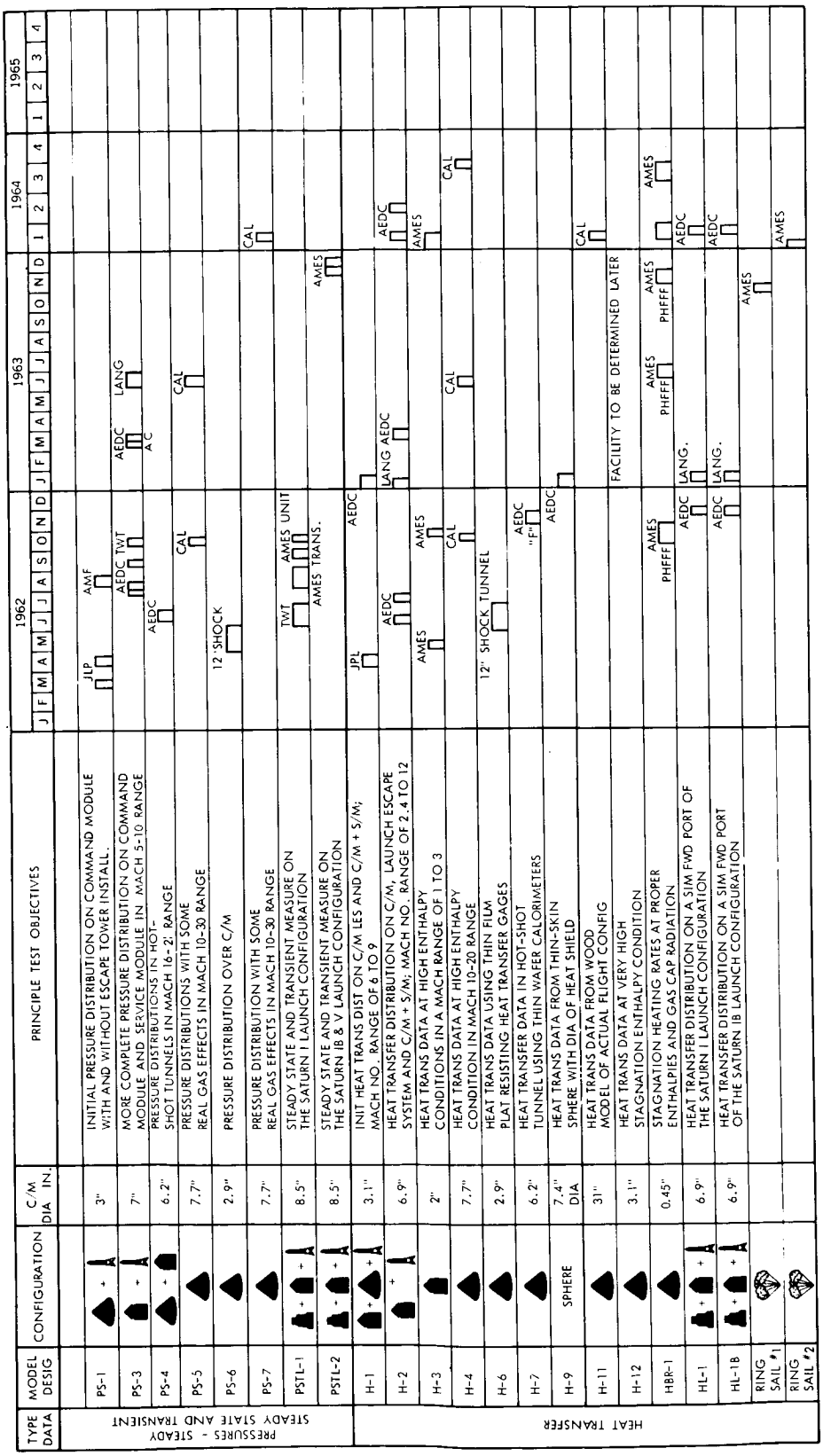

Figure 15-4. Apollo Wind Tunnel Test Program (Sheet 1 of 2)

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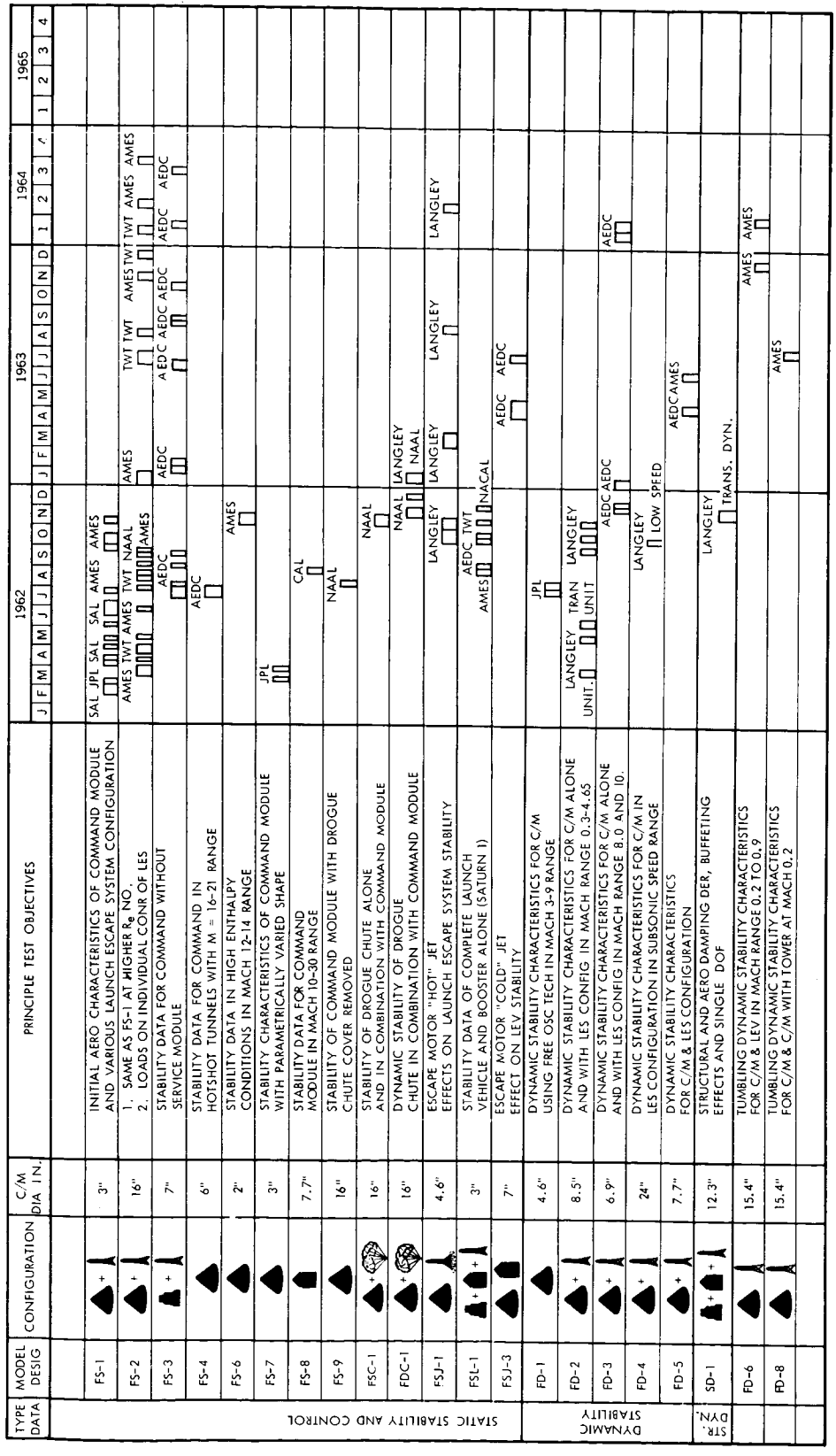

Figure 15-4. Apollo Wind Tunnel Test Program (Sheet 2 of 2)

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16.0 THERMAL PROTECTION SYSTEMS

16.1 SCOPE

The thermal protection system for the command module consists of three basic elements: the ablative material, the brazed-steel honeycomb substructure, and the thermal insulation. In general, the tests of this system will be designed to simulate the anticipated flight environment of the Apollo spacecraft during the following phases: boost, abort, earth orbit, translunar, lunar orbit, lunar return, and earth entry.

Developmental tests will be conducted by the heat shield subcontractor to evaluate the ablative material and the composite heat shield components. These tests will, in the early stages of development, consist of small scale tests on the individual materials for thermal and mechanical properties and will subsequently progress to tests on composite panels 2 by 3 feet in size. NAA will conduct performance evaluation tests to assure conformance to the procurement specifications. These tests will consist of design data tests and analysis verification tests.

Among the developmental and evaluation tests planned for the thermal protection system are mechanical and physical tests, dynamic tests, structural integrity tests, and thermodynamic tests. Tensile, shear flexure, compressive strength, specific heat, thermal expansion coefficient, and thermal conductivity properties of the ablative materials will be determined. Acoustical and vibrational environments will be simulated. Adhesive bond and large composite panel thermal exposure tests to verify the structural integrity of the heat shield ablative material and substructure will form an integral part of the development program. Thermodynamic tests conducted in plasma-arc tunnels and rocket engine exhausts will be used to determine the performance of the ablative material when exposed to the thermal environments applicable to the Apollo program. Space environment tests will be performed, depending on the capabilities of the available test facilities.

Design information will be obtained for verification of flight environments, for evaluation of ablative and structural components and assemblies, and for confirmation of the final design configuration.

In addition, the thermal and mechanical properties of the antenna window material, cryogenic insulation, and structural materials will be

[redacted]

determined, as required for thermal analysis for the Apollo spacecraft and Apollo systems.

16.2 SUBCONTRACTOR TEST PLAN

16.2.1 Objectives

16.2.1.1 Heat Shield

16.2.1.1.1 Ablative Materials. These materials will be tested for thermal and mechanical properties under conditions simulating, as much as possible, the anticipated flight environment. In addition, physical-chemical properties, such as emissivity, absorptivity, and decomposition temperatures, will be determined.

16.2.1.1.2 Composite Panel Tests. Composite panels consisting of the ablative material bonded to the substructure will be tested to determine the mechanical properties of the composite unit. In addition, the thermal-structural stress characteristics of the composite structure will be determined for conditions predicted throughout the Apollo mission. An important part of this test program will consist of determining the effectiveness of various types of adhesives under the extreme temperature cycles of the Apollo mission.

16.2.2 Test Plan

16.2.2.1 Aerothermodynamic Data Tests

Convective and radiative heat-transfer distribution for basic configuration.

16.2.2.2 Materials Performance Evaluation Tests

1. Materials performance tests during ascent heating
2. Materials screening tests
3. Materials properties during ablation
4. Material performance in laminar and turbulent flow
5. Material surface properties: transmittance, reflectance, and emissivity

[redacted]

6. Materials response to combined radiative and convective heating

7. Materials response to simulated trajectories

16.2.2.3 Materials Properties Tests

1. Thermal properties of both virgin and char materials

2. Mechanical properties of both virgin and char materials

16.2.2.4 Structures Tests

1. Flexural tests of composite beams and panels

2. Shear tests of bonding material at various temperatures

3. Thermal cycling tests of ablator and composite panel at low temperatures

4. Acoustic tests

5. Mechanical vibration tests

6. Design verification tests

7. Peel tests of bonding material over a temperature range of -260 F to +600 F

16.2.2.5 Qualification Tests on Composite 2- by 3-Foot Panels

1. Vibration tests for typical environments

   a. Ground handling
   b. Launch
   c. Boost
   d. Reentry

2. Shock tests - similar to vibration

3. Acceleration tests for typical flight environments

   a. Launch (7g to 15 milliseconds)
   b. Abort (3g lateral, 20g axial)
   c. Reentry (to 20g)

[redacted]

4. Induced time-temperature history test

5. Thermal-structural-stress analytical model

   a. Correlation of test data with predicted results
   b. Extrapolation to flight conditions
   c. Selection of qualification tests on basis of analytical model

16.3 S&ID TEST PLAN

16.3.1 Heat Shield Substructure

16.3.1.1 Objective

The substructure will be tested for thermal and mechanical characteristics over the temperature range anticipated under flight conditions. These tests will include (but not be limited to) the determination of thermal conductivity, heat capacity, and coefficient of thermal expansion, as well as vibration, flexure, and acoustic.

16.3.1.2 Test Plan

1. Thermal properties

   a. Thermal conductivity, heat capacity, density for virgin plastic, and char

   b. Effective heat of ablation, decomposition, and temperature profile through material

2. Mechanical properties

   a. Flexural strength and modulus
   b. Tensile strength and modulus
   c. Compression strength and modulus
   d. Bearing strength
   e. Poisson's ratio
   f. Panel shear
   g. Hardness
   h. Bonding and/or fastener

      (1) Tensile lap shear
      (2) Flatwise tensile
      (3) Block shear
      (4) Peel

[redacted]

16.3.2 Antenna Windows

16.3.2.1 Objective

Antenna window materials will be tested to determine the dielectric constant, electrical resistivity, and thermal properties, including shock resistance, under a simulated vacuum environment.

16.3.2.2 Test Plan

Antenna window material properties to be tested are as follows:

1. Dielectric constant
2. Electrical resistivity
3. Thermal conductivity
4. Thermal shock resistance
5. Thermal degradation
6. Ultraviolet and particulate radiation impingement
7. Static mechanical properties
8. Dynamic mechanical properties (vibration, acceleration, shock and acoustic noise)

16.3.3 Thermal Insulation

16.3.3.1 Objectives

The objectives of the insulation testing program are:

1. To evaluate candidate insulations for thermal and mechanical properties under simulated space environments

2. To select those materials having optimum desirable properties for use in the Apollo thermal protection system. (These materials will be evaluated in actual installed configurations to determine optimum fastening and installation techniques.)

16.3.3.2 Test Plan

Heat capacity measurements will be determined for the temperature range of +150 F to +600 F by using the closed cup drop calorimeter method. Thermal conductance determinations will be performed using three methods:

1. Guarded hot plate (temperature range +90 F to +900 F)

2. Liquid nitrogen comparator (-300 F to +300 F)

[redacted]

[redacted]

3. Liquid nitrogen guarded heater (-300 F to -30 F). Special fabricated specimens representing actual configurations will be tested to determine thermal properties and to develop insulation installation and fastening techniques.

16.3.3.3 Equipment

The following test equipment will be required:

1. Closed cup drop calorimeter
2. Guarded hot plate conductivity apparatus
3. Liquid nitrogen comparator
4. Liquid nitrogen guarded heater
5. Temperature recorders, potentiometers, vacuum pumps, and related laboratory equipment

16.3.3.4 Facilities

The tests will be performed at the S&ID EDL facilities.

16.3.3.5 Test Schedule

The thermal protection systems test schedule is presented in Figure 16-1.

16.3.4 Evaluation of the Service Module Sextant Insulation

16.3.4.1 Objectives

The objectives for evaluating the S/M sextant insulation are:

1. Determine the effective thermal conductances for insulation installed in the proposed configurations
2. Determine the relative effectiveness of the proposed insulation configurations
3. Determine the percentage of heat transfer due to structural heat shorts versus the percentage lost by radiation for the propellant tanks

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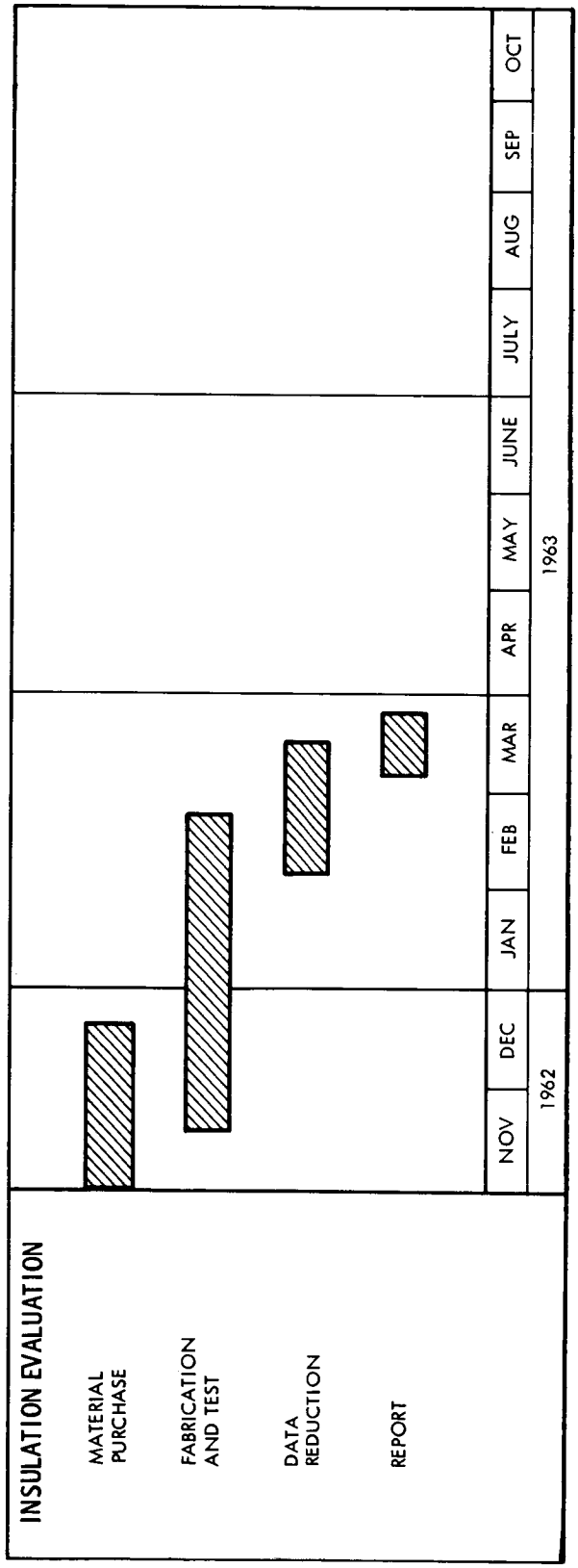

Figure 16-1. Thermal Protection Systems Test Schedule

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4. Develop and evaluate manufacturing skill in insulation blanket fabrication and installation

16.3.4.2 Test Plan

The S/M propellant sextant will be exposed to 10^{-5} torr and temperatures of -300 F and +250 F. The sextant will be held at each temperature and 10^{-4} torr for a maximum of five days, depending upon the thermal response time of the structure. Thermocouples that are located at key positions will be monitored to determine time-temperature histories, temperature gradients, heat loss paths, and the effective thermal conductivity of the insulated system.

16.3.4.3 Equipment

1. Vacuum chamber (10^{-5} torr)
2. LN_2 shroud
3. Heating blankets
4. Temperature recorders

16.3.4.4 Facilities

The tests will be performed at the LAD Apollo vacuum chamber. Manufacturing of the propellant sextant and the insulation blankets will be performed at S&ID.

16.3.4.5 Test Schedule

The service module sextant insulation test schedule is presented in Figure 16-2.

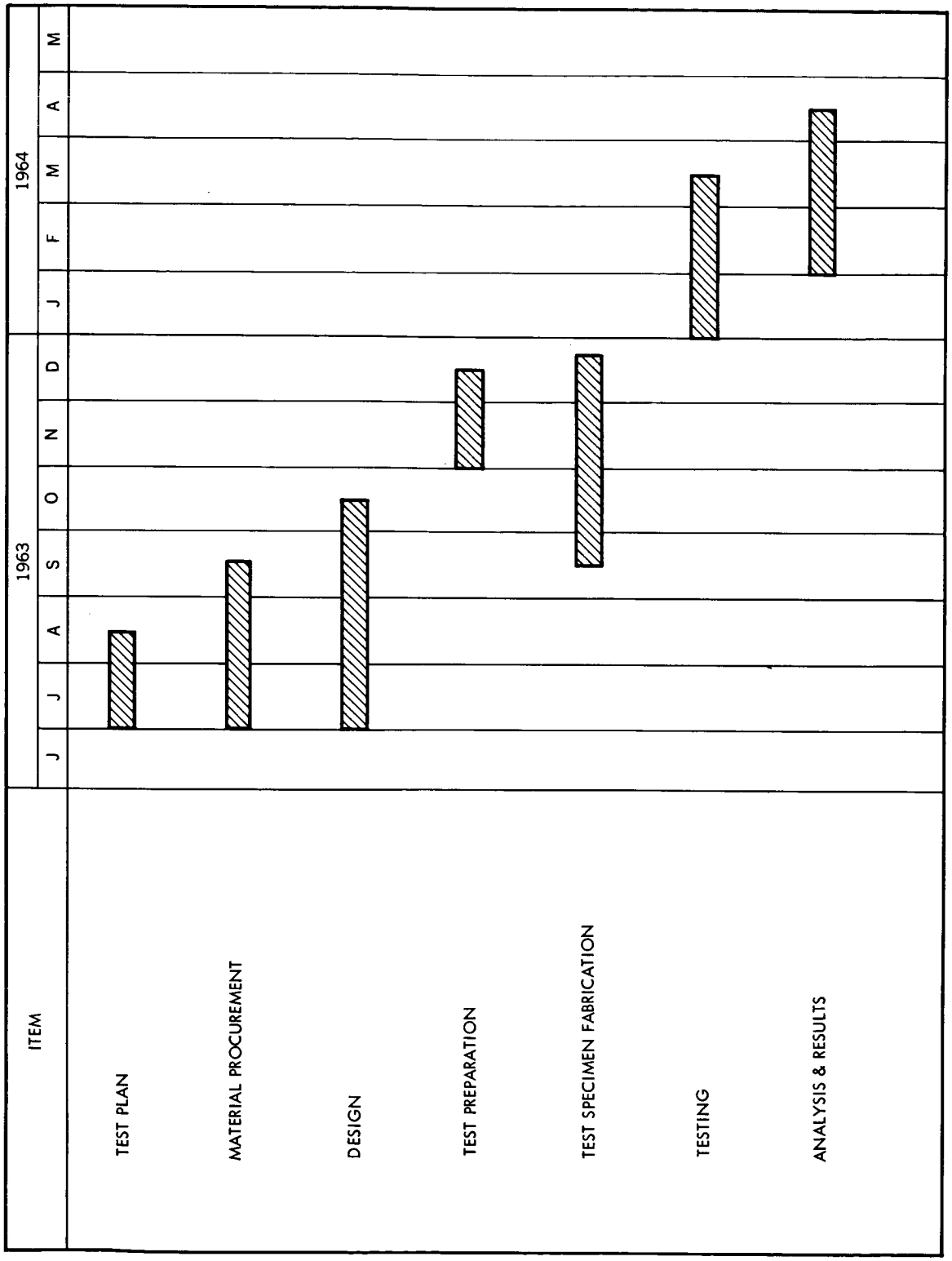

Figure 16-2. Service Module Sextant Insulation Test Schedule

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17.0 IN-FLIGHT TEST SYSTEM

17.1 SCOPE

Efforts concerning the design verification, evaluation, qualification, and reliability testing of the in-flight test system will be specifically divided between the subcontractor and S&ID. Test programs conducted by the subcontractor and S&ID will be integrated to the extent necessary to avoid redundancy and to provide a maximum confidence level in system performance and reliability.

The in-flight test system procurement, as of 1 August 1963, has not been placed; therefore, this section must await submission of the Preliminary Test Plan and the hardware delivery schedule by the selected subcontractor.

[redacted]

18.0 DISPLAYS AND CONTROLS

18.1 SCOPE

Panel assemblies furnished complete by the associate contractor or subcontractor will be tested by the associate contractor or subcontractor.

Panel assemblies fabricated and assembled in-house will be tested by NAA. The major components, such as meters, switches, etc., to be assembled into these panels will be tested by their respective subcontractors.

The main display console will be tested by NAA.

18.2 SUBCONTRACTOR TEST PLAN

The respective contractors will be responsible for performing the required development, acceptance, and qualification tests with the concurrency of the responsible design group—G&N, SCS, etc. The following panel assemblies are in this category:

1. Entry monitor display panel assembly
2. Flight director attitude indicator panel assembly
3. Attitude set and GPD panel assembly
4. ΔV display panel assembly
5. SCS control and mode select panel assembly
6. G&N computer control panel assembly

18.3 S&ID TEST PLAN

18.3.1 Panel Assembly In-House Fabrication and Assembly

The development, acceptance, and ground qualification tests of components and panel assemblies are the responsibility of the Displays and Controls group. The following panel assemblies are in this category:

1. Barometric indicator
2. Emergency detection system and sequencer display

3. SCS control and mode select
4. Master caution, UHF antenna select
5. Master caution
6. Reaction control system
7. Radiation, audio, cryogenic and ECS
8. Reaction control system
9. Crew safety control
10. O_2 warning
11. Fuel cells, electrical power system
12. Antenna control system
13. Communication, data link and service propulsion system

18.3.1.1 Major Purchased Components

Major components, such as the baro indicator, toggle switches, rotary switches, meters, and other special items purchased from subcontractors, will be tested by development tests to ascertain optimum operational verification, by acceptance tests to verify maintenance of operational levels of the equipment in production, and by qualification tests to prove the design capabilities of the equipment to function in the range of environments expected within the spacecraft during a flight. After successfully completing the above tests, the equipment will pass through receiving inspection before going to manufacturing for panel assembly.

18.3.1.2 Panel Assemblies

As circuit design progresses, development tests will be performed to ascertain the fulfillment of requirements and optimum operation. Records of these tests will become a part of the life history of the components. Upon completion of manufacturing assembly, each panel assembly will be acceptance tested to verify that the operational level has been maintained. Specimens will be chosen to be used for qualification testing, the quantity of the specimens being based upon the criticality of the particular panel assembly, as determined by the Reliability group. These tests are to verify

[redacted]

that the equipment as designed will fulfill the operational requirements in the environmental conditions of the spacecraft. Further tests will determine the design limit or failure level as a guide to design safety margin.

18.3.1.3 Console

The complete main display console, consisting of the panel assemblies mounted upon the substructure, will be subjected to a limited series of temperature, vibration, and shock tests to prove the design crew safety levels of the substructure and panels. The complete console must survive these tests with no mechanical disintegration.

18.3.2 Interface Area Tests

All panel assemblies with the exception of the entry monitor display and barometric indicator are display and control extensions of their parent system. As such, combined system tests and integrated system tests of the panels become a functional part of the tests of the parent system and will necessarily be integrated with those tests by the responsible system group. System compatibility, calibration, and procedures will be entirely dependent upon the parent system group. Displays and Controls, under these ground rules, becomes the supporting group responsible for maintaining the display and control panels through the various spacecraft checkout operations, with modification drawings, modified panels, and configurations of the console.

The entry monitor display is a completely independent system with its own sensing elements. After installation checkout, all testing will be accomplished by the system self-check capability. The times of these tests will be written into the countdown and flight procedures to cover necessary tests.

18.3.3 Caution and Warning

This system being a malfunction indicator for numerous systems is in the general category discussed in 18.3. The system has a further built-in self-check capability to exercise its own circuits to demonstrate their integrity. The use of this self-test capability will be written into the proper test procedures.

[redacted]

19.0 SIMULATION TEST PROGRAM

This section of the General Test Plan is currently being formalized and will be included in the 31 March 1964 issue. For preliminary information, refer to SID 63-1040, Apollo Simulation Plan.

[redacted]

[redacted]

20.0 ENTRY MONITOR SYSTEM

This section is being formulated and will be presented when completed.

[redacted]

NOMENCLATURE

A listing of the special nomenclature and abbreviations used in this report is presented. These listings may appear interchangeably with their full definitions in the text. Accepted abbreviations for units of physical measurement such as volts, ohms, etc. are not included.

Abbreviation	Definition
AEDC	Arnold Engineering Development Center
AFMTC	Air Force Missile Test Center
AFRM	Airframe
AGAP	Attitude gyro and accelerometer package
AGC	Aerojet-General Corporation
AGC	Automatic Gain Control
AGC	Apollo guidance computer
AGREE	Advisory group on reliability of electronic equipment
AMR	Atlantic Missile Range
ATO	Apollo Test and Operations
BAL	Balance
BCD	Binary coded decimal
B-#	Boilerplate - # (with specific number)
B/M	Bench maintenance
BOD	Beneficial Occupancy Date
BMAG	Body-mounted attitude gyros

[redacted]

Abbreviation	Definition
B/P	Boilerplate
CCMTA	Cape Canaveral Missile Text Annex
C&D	Controls and displays
CDS	Communications and data subsystems
CDU	Coupling display unit
CG	Center of gravity
C&IS	Communications and instrumentation system
C/M	Command module
C/O	Checkout
C-O	Crew operated
CP	Control panel
CTU	Central timing unit
CVR	Change verification record
DEA	Display electronic assemblies
DF	Direction finding
DOD	Department of Defense
DOF	Degrees of freedom
DP	Design proof
DPT	Design proof test
DSIF	Deep Space Instrumentation Facility

[redacted]

[redacted]

Abbreviation	Definition
DVD	Differential velocity display
EBW	Exploding bridge wire
ECA	Electronic control assembly
ECS	Environmental control system
EDL	Engineering Development Laboratory (S&ID Dny)
ELS	Earth landing system
EMI	Electromagnetic interference
EPS	Electrical power system
ET	Escape tower
FDAI	Flight director attitude indicator
FM	Frequency modulation
FAX	Facsimile transmission
G, g	Acceleration of gravity
G&NS	Guidance and navigation system
GOSS	Ground operational support system
GP	General purpose
GPI	Gimbal position indicator
GSE	Ground support equipment
HAA	High-altitude abort
HBW	Hot bridge wire
H/A	Hazardous area

[redacted]

[redacted]

Abbreviation	Definition
IFT&M	In-flight test and maintenance
IMCC	Integrated Mission Control Center
IMU	Inertial measurements unit
INT	Interior
INST REF	Instrument reference
IRIG	Inter-range instrumentation group
L-	Time before launch (days)
LAD	Los Angeles Division (or NAA)
L/D	Length-diameter ratio
LEM	Lunar excursion module
LEV	Launch escape vehicle
LES	Launch escape system
LJII	Little Joe II
LOR	Lunar orbit rendezvous
LSS	Life support system
L/V	Launch vehicle
MDSS	Mission data support system
M-#	Mock-up - # (with specific number)
Max q	Maximum dynamic pressure
MEE	Mission essential equipment

[redacted]

[redacted]

Abbreviation	Definition
MIT	Massachusetts Institute of Technology
MLT	Mission life test
MNEE	Mission non-essential equipment
MSC	Manned Spacecraft Center (NASA, Houston, Texas)
MTBF	Mean time before failure
MTTR	Mean time to repair
NAA	North American Aviation
NASA	National Aeronautics and Space Administration
O/F	Oxidizer-to-fuel ratio
OPS	Operations
OTP	Operational test procedure
PA	Power amplifier
PACE-S/C	Prelaunch automatic checkout equipment - spacecraft
PAM	Pulse amplitude modulation
PCM	Pulse coded modulation
P_c	Pressure chamber
PDM	Pulse duration modulation
P_f	Probability of failure
P_{f_p}	Probability of performance failure
P_{f_s}	Probability of stress failure
PFRT	Preliminary flight rating test
POD	Prelaunch Operations Division (NASA)

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Abbreviation	Definition
P_s	Probability of success
PSA	Power and servo assembly
PTT	Push to talk
PUCS	Propellant utilization control system
P&WA	Pratt & Whitney Aircraft
R/B	Radar beacon
R/C	Radio command
RCC	Range control center
RCS	Reaction control system
R&D	Research and development
REG	Regulator
RF	Radio frequency
RFI	Radio frequency interference
RFWAR	Requirements for work and resources
RGP	Rate gyro package
R&Z	Range and zero
SA	Saturn Apollo
SCAT	Space communications and tracking
SCD	Specification control drawing
SCIP	Self-contained instrumentation package
SCO	Subcarrier oscillator
SCR	Silicon-controlled rectifier

[redacted]

Abbreviation	Definition
SCT	Scanning telescope
S/C	Spacecraft
S/C_a	Spacecraft adapter
SCS	Stabilization and control system
SEP	Space electronic package
S&ID	Space and Information Systems Division (of NAA)
S/M	Service module
SOL	Solenoid
SOFAR	Sound fixing and ranging
SPS	Service propulsion system
STU	Systems test unit
SXT	Sextant
T-	Time before launch
T-O	Time of launch
T+	Time after launch
T/M	Telemeter
TP	Test point
TPA	Test preparation area
TPS	Thermal protection system
T/R	Transmitter receiver (combination in two packages)
TWT	Traveling wave tube
TWX	Teletype wire transmission

[redacted]

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Abbreviation	Definition
UDMH	Unsymmetrical dimethyl hydrazine
VCO	Voltage controlled oscillator
VLF	Vertical launch facility
VSWR	Voltage standing wave ratio
WSMR	White Sands Missile Range
XCVR	Transceiver (transmitter receiver in one package)

[redacted]

DEFINITION OF TERMS

ABLATE	To carry away; to remove by cutting or erosion, melting or evaporation. To undergo ablation; to become melted or vaporized and removed at a very high temperature.
ABORT	An uncompleted missile flight or an uncompleted hold-down test resulting from a failure of equipment or of a system other than the one undergoing test. In a tactical operation (simulated or real) a missile failure either on the ground or in flight; a missile that fails to complete a programmed flight.
ADAPTER	Flange or extension of a vehicle stage or section providing a means of fitting another stage or section to it.
AEROBALLISTICS	Term derived from aerodynamics and ballistics, dealing primarily with the motion of bodies whose flight path is determined by applying the principle of both sciences to different portions of the path.
AEROTHERMODYNAMIC BORDER	Area above an altitude of about 100 miles where the atmosphere becomes so rarefied that there is no longer any significant heat-generating air friction on the skin of vehicles.
AIRFRAME	Assembled structural and aerodynamic components of an aircraft or missile.
ALBEDO	The ratio of light reflecting from an unpolished surface to the light falling upon it. Term is used in reference to light reflected from the moon or planets.
AMBIENT CONDITIONS	Environmental conditions such as pressure or temperature; naturally existing conditions.
ANTHROPOMORPHIC	Human-like; related to or designed for the human body.

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APOLLO	NASA designation for follow-up manned space-flight program to Project Mercury manned orbital mission. Apollo spacecraft is to be suitable for manned earth-orbiting laboratory, manned circumlunar flight, manned lunar landing, and return.
ATLANTIC MISSILE RANGE (AMR)	A 5000- to 6000-mile instrumented range for testing ballistic and guided missiles located between Cape Canaveral, Florida, and a point beyond Ascension Auxiliary AFB, near the middle of the South Atlantic.
ATTITUDE	Orientation of an air vehicle as determined by the inclination of its axis to a frame of reference, usually the earth.
ATTITUDE JETS	Sometimes called steering jets, attitude-control jets or roll, pitch, and yaw jets; fixed or movable gas nozzles on a rocket, missile, or satellite operated continuously or intermittently to change attitude or position.
AXIS, AXES	Reference axes in the Apollo spacecraft are as follows:
X-axis	The X-axis is parallel to the nominal launch axis and is positive in the direction of initial flight.
Y-axis	The Y-axis is normal to the X-axis and is positive to the right of a crewman when the crewman is in his seat facing toward positive "X."
Z-axis	The Z-axis is normal to both the X- and Y-axes and is positive in the direction of the crewman's feet when he is in his seat.
BACKUP	Designed to immediately follow an earlier space system or a project to complement the latter or take advantage of new techniques and processes; a system that can replace a failed system.

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BENCH MAINTENANCE EQUIPMENT	Equipment supporting component and subsystem testing; facilities capable of isolating, defining, and providing remedial action to malfunctions.
BIOMEDICINE	Combined discipline of biology and medicine for analysis of human tolerances to and protection against environmental variances.
BOILERPLATE	Simulated module for predevelopmental and developmental tests leading to the design of the spacecraft module.
BOOSTER ENGINE	An engine, especially a booster rocket, that adds thrust to the thrust of the sustainer engine, or provides propulsion for a special phase of flight.
BREADBOARD MODEL	An assembly of preliminary circuits and parts to prove the feasibility of a device, circuits, equipment, system or principle in rough or breadboard form without regard to the eventual over-all design or form of parts.
BRIDGE WIRE	The ignition resistor filament. The bridge wire heats the primary explosive to initiate the explosion.
CELESTIAL GUIDANCE	Mechanically or electrically recorded navigational tables, computers, and other instruments and devices that sight stars, calculate position, direct, and control the spacecraft.
CENTRIFUGE	A large motor-driven apparatus with a long rotating arm at the end of which human and animal subjects or equipment can be revolved at various speeds to simulate accelerations encountered in high-performance vehicles.
CHECKOUT	A sequence of operational and calibrational tests needed to determine the condition and status of a required operation or function.

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COASTING FLIGHT	The flight of a rocket or other vehicle between burnout or thrust cutoff of one stage and ignition of another, or between final burnout and summit altitude or maximum range. Also the unpowered portion of an interplanetary flight.
COMMAND MODULE	Personnel and control vehicle in the Apollo spacecraft configuration containing command and communication facilities and crew provisions.
COMPATIBILITY	The quality that permits an item to function in harmony with other equipment and fulfill all design objectives.
CONFIGURATION	The physical nature of an item; the physical arrangement of components which comprise a spacecraft and its dimensions.
CONSOLE	Master instrument panel from which rocket and missile launchings and test are controlled; a group of controls, indicators, and similar electrical or mechanical equipment that is used to monitor readiness of and/or control specific functions such as missile checkout, countdown and launch operations.
COUNTDOWN	Series of numbered events and checks that take place from the start of rocket-launching operations until the rocket lifts off the launch stand.
CRYOGENIC FUEL	A rocket fuel that either in itself is kept at very low temperatures or combines with an oxidizer kept at very low temperatures.
CUTOFF	The shutting off of a liquid or solid-propellant combustion process of a rocket engine, causing a rapid drop toward zero thrust (intentional command action).
DEEP SPACE INSTRUMENTATION FACILITY (DSIF)	Communication equipment capable of contacting and tracking spacecraft beyond normal ranges. DSIF facilities are located at Woomera, Australia; Johannesburg, South Africa; and Goldstone, California

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DEMONSTRATE	Denotes the occurrence of an action or an event during a test. The accomplishment of this type of objective requires a qualitative answer. The answer will be derived through the relation of this action or event to some other known information or occurrence. This category of objectives implies a minimum of system instrumentation and/or that information be obtained external to the test vehicle.
DESIGN VERIFICATION TEST	Basic development test used to determine the adequacy of the design over the anticipated operating conditions. A design verification test is always conducted by Engineering and on a breadboard level.
DETERMINE	Denotes the measuring of performance of any unit or system. This category implies the quantitative investigation of over-all operation, which includes, generally, instrumentation for measuring basic inputs and outputs of the unit or system. The information obtained should indicate to what extent the system is operating as designed. The instrumentation should allow performance deficiencies to be isolated to either the system or the system inputs.
DRAG	The resistance of a body to motion in a medium such as air.
DRY WEIGHT	Weight of a rocket vehicle without its fuel and usually without payload.
EARTH LANDING SUBSYSTEM (ELS)	Acceleration-decreasing equipment for return to the earth's surface after atmospheric reentry; may consist of a parachute system, a flexible aerodynamic glider configuration, or both.
ENGINEERING DEVELOPMENT PART	A part or unit to be employed in a breadboard design.
ENVIRONMENTAL CONTROL SUBSYSTEM (ECS)	The components controlling crew conditions in the spacecraft; governing factors of atmosphere, pressure, and temperature; and providing support for spacesuit conditions in event of cabin decompression or extra vehicular operations.

ESTABLISH	Denotes gathering information for the development of ground procedures and operating techniques. Objectives in this category are not necessarily dependent on analytic studies.
EVALUATE	Denotes the measuring of performance of any unit or system, as well as the performance and/or interaction of its sections or subsystems that are under investigation. The accomplishment of objectives of this type requires quantitative data on the performance of both the unit or system, and its sections or subsystems will be analyzed for their contribution toward performance of the unit or system. This category will provide the most detailed information of any of these categories.
FALLAWAY SECTION	Any section of a rocket vehicle that is cast off and falls away from the vehicle during flight, especially such a section that falls back to earth.
FIRST MOTION	First indication of motion of the missile or test vehicle from its launcher. Synonymous with "takeoff" for vertically launched missiles.
FLIGHT READINESS FIRINGS (FRF)	A missile system test consisting of the complete firing of the liquid-propellant engines of a rocket missile while it is restrained in its launching stand to verify the readiness of the missile for a flight test or mission.
FREE-FLIGHT TRAJECTORY (Free Fall Ellipse)	That part of a ballistic missile's trajectory that begins with thrust cutoff and ends at reentry.
FUEL CELL	A source of electrical power analogous to a common electrical cell with the reactants continually replenished from an external supply.
GAMMA RADIATION	Electromagnetic radiation having a high degree of penetration similar to X-rays originating from the nucleus.

GEMINI	NASA follow-up program to Mercury; a two-man spacecrate to demonstrate rendezvous and docking techniques, longer orbital flights (to 14 days), controlled reentry, and landing.
GIMBALED MOTOR	A rocket motor mounted on a gimbal, i. e., on a contrivance having two mutually perpendicular axes of rotation so as to correct pitching and yawing.
GODDARD SPACE FLIGHT CENTER (GSFC)	NASA research center at Greenbelt, Maryland, named for Robert H. Goddard, American rocket pioneer.
GOLDSTONE TRACKING FACILITY	A deep space instrumentation facility located at Army's Camp Irvin, Barstow, California, using a radiotelescope and operated for NASA by Jet Propulsion Laboratory (JPL).
GO NO-GO	A missile launch controlled at the end of the countdown as to permit an instantaneous change in decision on whether or not to launch.
GROUND OPERATIONAL SUPPORT SYSTEM (GOSS)	Network of tracking stations, fixed and mobile, air, ground, and seaborne to communicate with, track, and telemeter spacecraft and satellites.
GROUND SUPPORT EQUIPMENT (GSE)	All ground equipment that is part of the complete spacecraft system and that must be furnished to ensure its support. All implements or devices required to maintain the functional operational status of the spacecraft are included. In the Apollo program, bench maintenance equipment, combined system test unit, and prelaunch automatic checkout equipment comprise the GSE.
GUIDANCE	(1) The process of intelligent gathering and maneuvering required by a missile, probe, or space ship to reach a specified destination. (2) General term includes entire scheme: sensing devices, computers, and servo systems.

[redacted]

HEAT SHIELD	An ablative protective covering to ensure spacecraft and crew survival through the hypertemperatures of atmospheric reentry.
HEAT SINK	A device that absorbs heat energy.
HOT TEST	Propulsion system test conducted by actually firing the propellants. A hot test may be live, static, or conducted in a confined place.
INERTIAL GUIDANCE	An onboard guidance system for space and satellite vehicles where gyros, accelerometers, and possibly a gyro-stabilized platform satisfy guidance requirements without use of any ground-located components. The system is entirely automatic, following predetermined trajectory.
INFRARED LIGHT	Light in which the rays lie just below the red end of the visible spectrum.
INITIATOR	A primary explosive mixture used as a primer, detonator for caps which initiates the explosion of blasting propellant, bursting explosives at the desired moment.
INTERIM QUALIFIED	A term used to describe the status of a component or system scheduled for use in early flights wherein the basically essential qualification tests have been successfully completed as related to the specific flight objectives.
INVERTER	A converter to a-c power from a d-c source.
JET STEERING	The use of fixed or movable gas jets on a space weapon, ballistic missile, or sounding rocket for thrust vector control to steer it along a desired trajectory, during both propelled flight and after thrust cutoff.
KELVIN SCALE (K)	A temperature scale that used Centigrade degrees as gradients and absolute zero for zero. Zero Kelvin equals -460 F or -273 C.

LANGLEY RESEARCH CENTER	NASA installation in Hampton, Virginia, responsible for technical research in development and improvement in both atmospheric and space flight.
LAUNCH WINDOW	The allowable limits of launch time that will allow a spacecraft to achieve successful injection into programmed flight path.
LAUNCH ESCAPE SUBSYSTEM (LES)	The components for command module recovery in case of mission abort after launch and prior to orbit. The system consists of the launch escape motor, the launch escape tower, and the tower jettison motor.
LIQUID HYDROGEN	Liquid rocket fuel that develops a specific impulse, when oxidized by liquid oxygen, ranging between 317 and 364 seconds depending upon the mixture ratio.
LIQUID OXYGEN	Oxygen supercooled and kept under pressure so that its physical state is liquid. Used as an oxidizer in a liquid-fuel rocket.
LITTLE JOE (I, II)	A solid-rocket test vehicle developed by General Dynamics. I was used especially to test the Mercury capsule, and II will be used to test the Apollo spacecraft.
LUNAR EXCURSION MODULE	The two-man vehicle that will land on the moon after the Apollo spacecraft enters lunar orbit.
LUNAR ORBITAL RENDEZVOUS	The concept for manned lunar landing adopted by NASA wherein the lunar excursion module leaves the spacecraft, lands on the moon, and later returns to the orbiting spacecraft. The excursion module will be jettisoned as the spacecraft leaves lunar orbit.
MANNED SPACECRAFT CENTER (MSC)	NASA headquarters responsible for development and operation of manned space vehicles (Mercury, Gemini, Apollo), located in Houston, Texas.

[redacted]

MARSHALL SPACE FLIGHT CENTER (MSFC)	NASA operation responsible for design and development of space launch vehicles (Saturn, Advanced Saturn, Nova), located in Huntsville, Alabama.
MOCK-UP	A full-scale, three-dimensional representation of a complete spacecraft, individual module, and/or related equipment. Based on permanence and difficulty of alteration, mock-ups are graded as "soft," "semi-hard," and "hard."
MODULE	A combination of components, contained in one package or so arranged that together they are common to one mounting, which provides a complete function. (See command module, service module, lunar excursion module, etc.)
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)	Civilian agency, sponsored by the U. S. Government, with research and development jurisdiction in aeronautical and space activities except those activities peculiar to or primarily associated with the development of weapon systems, military operations, or the defense of the United States.
NAUTICAL MILE (NM)	A measure of distance equal to 6,076.103 feet or approximately 1.15 mile.
OBTAIN DATA	Denotes gathering engineering information that is to be measured to augment the general knowledge required in the development of the over-all spacecraft. This category may also be used for supplemental investigation, such as environmental studies, ground equipment studies, etc. The degree of instrumentation is not implied by this definition.
OPTICAL STAR TRACKER	A star tracker that locks onto the light of a particular celestial body. Distinguished from a radiometric star tracker. (See star tracker.)
OXIDIZER	A rocket propellant component, such as liquid oxygen, nitric acid, fluorine, and others, that supports the combustion of a fuel.

PAD	A permanent or semipermanent load-bearing surface constructed or designed as a base upon which a launcher can be placed. Short for launch pad.
PITCH	The movement about an axis that is at once perpendicular to the Apollo longitudinal axis and horizontal to the Y-axis of the spacecraft.
PRE-QUALIFIED	A pre-qualified part or component is one that has been scheduled as the one most likely to succeed in the qualification program and will be used in production runs as well as during developmental test or early flight test prior to qualification.
PRESSURIZED SUIT	A garment designed to provide pressure upon the body so that respiratory and circulatory functions may continue normally, or nearly so, under low-pressure conditions, such as occur at high altitudes or in space without benefit of a pressurized cabin.
PROGRAMMED ROLL	An automatically controlled roll of a ballistic missile or satellite, usually executed during its vertical ascent before pitch-over.
PROGRAMMED TURN	The turn of a ballistic missile from vertical motion, after lift-off, to a curved path approximating the desired powered flight trajectory prior to the initiation of guidance.
PROPELLANT	A liquid or solid substance burned in a rocket for the purpose of developing thrust.
PROTOTYPE	A model suitable for complete evaluation of mechanical and electrical form, design, and performance. It is in final mechanical and electrical form, employing approved parts, and completely representative of the final equipment.
QUALIFICATION OF PART, COMPONENT, OR SYSTEM	A part, component, or system is considered qualified by definition after it has successfully completed all of the prescribed tests associated with relevant control specifications.

READOUT	A radio transmitter transmitting data either instantaneously with computation of the data or by play of a magnetic tape on which the data have been recorded.
RECOVERY	The act of retrieving a portion of a launched missile or satellite that has survived reentry.
REENTRY	Return of a part of a space vehicle to the atmosphere after flight above the sensible atmosphere.
RELIABILITY	Reliability is the probability of performing without failure a specified function, under given conditions, for a specified period of time. It deals with the failure rates in time of specified items.
RETROROCKET	Relatively small rocket unit, usually solid propellant, installed on a rocket-propelled vehicle and fired in a direction opposite to the main motion to decelerate main unit.
ROLL	The movement of Apollo about its longitudinal (X) axis.
SATURN	The sun's sixth planet. A NASA rocket engine cluster in research and development expected to develop some 1,500,000 pounds of first-stage thrust. The Apollo launch vehicle.
SEPARATION	Moment when a full stage, half stage, a warhead, or a nose cone is separated from the remainder of the rocket vehicle; the moment when staging is accomplished.
SERVICE MODULE	Apollo module carrying propulsion equipment, fuel, reaction control systems, and communications power. It is used for thrust after booster separation, mid-course correction, lunar orbit, lunar orbit ejection, and earth return midcourse correction. It is jettisoned prior to reentry.
SERVICE PROPULSION SYSTEM	Engine and associated equipment providing thrust for service module functions. (See SERVICE MODULE.)

SOFT LANDING	Landing on the moon or other spatial body at such slow speed as to avoid damage of landing vehicle. Soft landings on moon are anticipated by use of retrorockets.
SOLAR FLARE	Solar phenomenon that gives rise to intense ultraviolet and corpuscular emission from the associated region of the sun. This affects the structure of the ionosphere and interferes with communications.
SOLID PROPELLANT	A propellant in solid condition including all the ingredients necessary for sustained chemical combustion, such as a compound of fuel and oxidizer, usually in plastic caked form. It burns on its exposed surface, generating hot exhaust gases to produce a reaction force.
SPACECRAFT	In the Apollo program, any component or combined components of the flight vehicle not part of the launch vehicle: launch escape subsystem, command module, service module, adapter, or any combination of these.
SPECIFIC IMPULSE	The thrust produced by a jet-reaction engine per unit weight of propellant burned per unit time, or per mass of working fluid passing through the engine in unit time. It is equal to thrust in pounds divided by weight flow rate in pounds per second.
STABILIZATION AND CONTROL SUBSYSTEM (SCS)	An Apollo monitor system linked to navigation and guidance system, display system, and reaction control subsystem indicating spacecraft attitude (roll, yaw, or pitch).
STAGE	In a rocket vehicle powered by successive units, one or other of the separate propulsion units.
STAGNATION POINT	The location on a surface in an airstream where the air flow is zero.

STAR TRACKER	A telescopic instrument on a missile or spacecraft that locks onto a celestial body and gives guidance to the missile or other object during flight.
STATIC TESTING	Testing of a missile or other device in a stationary or holddown position, to verify structural integrity, to determine the effects of limit loads, or to measure thrust.
SYSTEMS ENGINEERING	Process of applying science and technology to the study and planning of an over-all aerospace vehicle system, whereby relationships of various parts of the system and the use of various subsystems are fully planned and integrated prior to time hardware designs are committed.
TELEMETERING	The technique of recording space data by radioing an instrument reading from a rocket to a recording machine on the ground.
THEODOLITE	A sighting and measuring telescopic instrument that gives a reading on horizontal or vertical angles.
TRAJECTORY	The path described by a missile or a space vehicle.
TRANSFER ELLIPSE	Path followed by a body moving from one elliptical orbit to another.
ULLAGE	The amount of fluid by which a tank falls short of being full; the loss through evaporation, spilling, or consumption; the amount remaining that cannot be drained from an emptied tank or container.
UMBILICAL	Any one of several electrical or fluid lines connected between the ground support operation and an uprighted rocket missile or space vehicle before launch.
UNSYMMETRICAL DIMETHYLHYDRAZINE (UDMH)	Rocket fuel which with aerozine will power the Apollo spacecraft.

VECTOR STEERING	Vernacular for a steering method where one or more thrust chambers are gimbal mounted so that the direction of the thrust force (thrust vector) may be tilted in relation to the center of gravity of the missile to produce turning.
VELOCITY VECTOR	Combination of two ballistic missile trajectory values: the speed of the missile's center of gravity at a designated point on the trajectory and angle between local vertical and the direction of the speed.
WHITE SANDS MISSILE RANGE (WSMR)	A proving ground in New Mexico under the control of the Army Ordnance Missile Command; supports Apollo abort tests.
YAW	Lateral movement of the Apollo spacecraft along the Z-axis in line of flight.

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